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A FIRST BOOK

OF

ELECTRICITY AND MAGNETISM.

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A FIRST BOOK

OF

ELECTRICITY AND MAGNETISM,

FOR THE USE OF

ELEMENTARY SCIENCE AND ART, AND ENGINEERING
STUDENTS, AND GENERAL READERS.

BY

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School, Croydon; Author of "Practical Electrical Notes and Definitions."*

WITH ORIGINAL QUESTIONS, LIST OF APPARATUS,
AND COMPLETE INDEX.

Ruled pages for Notes.

WITH EIGHTY-FOUR ILLUSTRATIONS.

LONDON:
WHITTAKER AND CO., 2, WHITE HART STREET,
PATERNOSTER SQUARE.
1891.

CHISWICK PRESS:—C. WHITTINGHAM AND CO., TOOKS COURT,
CHANCERY LANE.

PREFACE.

THE excellent elementary text-books of Silvanus Thompson, Stewart and Gee, Jamieson, and some others, on the science of Electricity and Magnetism, are not elementary in the strict sense of the word; they are somewhat difficult reading for the beginner,—especially the young or ill-educated beginner.

My experience as a teacher of Electricity and Magnetism prompted me to write this book; for I felt sure, as other teachers must have, that many nonchalant, dull, and backward students would be led to take a greater interest in their work, had they but an easy introduction to their text-book, such as this is intended to be.

It has been my endeavour to use the simplest possible language, to be careful in the proper use of terms and phrases, discarding those which are superfluous or ancient; and, above all, to write in accordance with the latest accepted ideas. I have not, however, thought it advisable, in this elementary work, to touch upon the theories of Dr. Oliver Lodge.

For the information of teachers under the Science and Art Department, I may mention that this book covers the syllabus of the elementary stage. For their use, I have inserted a list of apparatus at the end of the book.

Two of my students, MM. Checker and Cullingford, have greatly assisted me in the preparation of some of the drawings.

I shall be most pleased to receive suggestions as to the improvement of the work, and to hear of any errors, difficulties in phraseology, etc., that may be noticed.

In a forthcoming *Second Book of Electricity and Magnetism*, I hope to cover the ground of the Advanced Syllabus of the Science and Art Department, and to enter into the consideration of the construction of apparatus.

W. PERREN MAYCOCK.

"MILBER," WADDON, SURREY,
Oct. 1891.

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A FIRST BOOK OF
ELECTRICITY AND MAGNETISM.

INTRODUCTION.

THE science of Electricity and Magnetism may be divided into three branches: **Magnetism**; **Electrokinetics**, or electricity in motion; and **Electrostatics**, or electricity at rest.

PART I.

MAGNETISM.

1. **Magnets.** A magnet has the power of attracting or picking up pieces of iron or steel.

2. **Lodestone.** A certain black or brown-coloured stone which is dug out of the earth, and from which iron may be extracted, naturally possesses the magnetic power of attracting iron, as may be shown by dipping a piece into a heap of tacks or iron filings. If it be hung up from its middle by a length of very fine untwisted thread, it will always be found to come to rest in a certain position, a particular part of it pointing towards the north, while the opposite end points south.

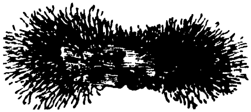

FIG. 1. LODESTONE.

Such stone is called *lodestone*, which means leading-stone, from the fact that it was used in early ages as a compass.

3. **Hardening Steel.** Steel is a mixture of iron and carbon. A piece of steel which has been heated all over to bright redness, and then quickly dipped into cold water, will be found to have become much harder and more brittle than it was at first. The steel will not be hardened unless dipped in the water while it is at a bright red heat. To ascertain if the hardening has been successfully performed, it is only necessary to rub the steel with a smooth file. If hard, the file will slip over the steel without cutting it. If the steel be overheated, *i.e.*, to a white heat, it will be to a certain degree spoilt.

4. **Magnetising Steel by means of a piece of Lodestone.** Take, say, four inches of steel wire, harden it, and rub it a dozen times from end to end with a piece of lodestone. Dip the wire into iron filings or tacks, and it will pick some of them up. This proves that the piece of steel has become magnetised.

5. **How to tell a Magnet.** If we had two pieces of hardened steel of exactly the same size, one of which was magnetised and the other not, there are three ways in which we might find out which was the magnetised piece: *First*, if both pieces be laid in a heap of iron filings, the filings will stick to the ends of the piece which is magnetised, as shown in Fig. 2; but the piece which

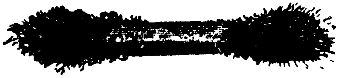

FIG. 2. BAR MAGNET.

is not magnetised will have no filings sticking to it. *Second,* suspend each piece in turn in a copper wire stirrup at the end of a length of untwisted silk thread, and make sure that it is quite balanced (Fig. 3). It will be found that one of them will always come to rest pointing north and south, while the other will rest in any position. The piece which points north and south is, of course, the magnetised one.

The third method of ascertaining whether a piece of steel is magnetised or not, is mentioned in § 15. After this, instead of troubling to write the words north and south, we shall use the letters N. and S.

6. **Artificial and Natural Magnets.** Lodestone magnets are sometimes called *natural magnets,* because they are found already magnetised. All other magnets are termed *artificial magnets.*

7. **Poles of a Magnet.** Every magnet has two ends, at which it will be found that the magnetic power of attraction is strongest. These ends are therefore called the *poles* of the magnet. The end or pole which turns towards the N. when the magnet is freely suspended, is called the *N. pole;* and that which turns towards the S., is called the *S. pole.*

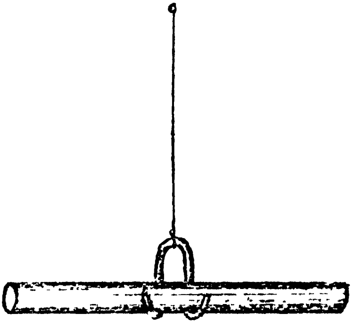

FIG. 3 SUSPENDED BAR OF STEEL.

8. **Electro-Magnet.** Take a bar of soft iron (*i.e.*, iron

which has been heated to redness, and then allowed to cool gradually), wind a length of covered copper wire[1] round it, and send a current of electricity from a battery (§ 66) through the wire. The iron will be magnetised, and will remain so as long as the current is "flowing," but directly the current is stopped, the iron will lose its magnetism (Fig. 4).

9. **Electro-Magnets and Permanent Magnets.** Such a magnet as the one just described is called an *electro-magnet,* to distinguish it from a steel or *permanent magnet,* which when once magnetised, retains its power.

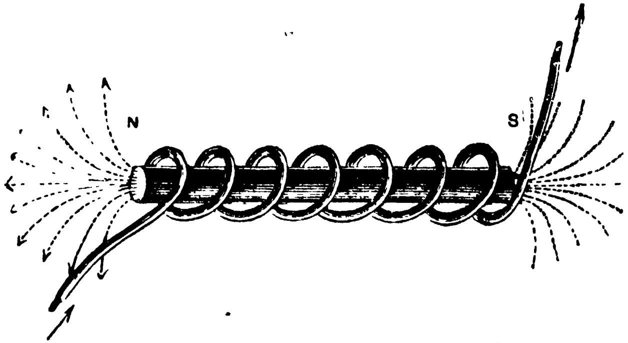

FIG. 4. MAGNETISATION BY AN ELECTRIC CURRENT.

10. **Bar and Horseshoe Magnets.** Straight magnets are called *bar magnets,* to distinguish them from *horseshoe magnets,* in which the magnet is bent into a form some-

---

[1] Copper wire for winding electro-magnets, etc., must have a covering of cotton, silk, india-rubber, gutta-percha, or other substance which will not allow electricity to "flow" across the coils, when touching, instead of through them.

thing like a horseshoe, so as to bring both poles near each other, and thus enable them to act together upon the same piece of iron. It is for this reason that the horseshoe-shaped magnet is most generally used. Fig. 5 represents a bar and a horseshoe permanent magnet; and Fig. 6, a bar and a horseshoe electro-magnet.

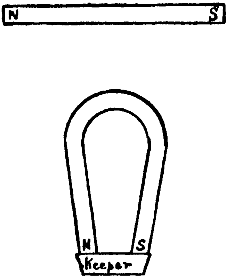

FIG. 5. PERMANENT MAGNETS.

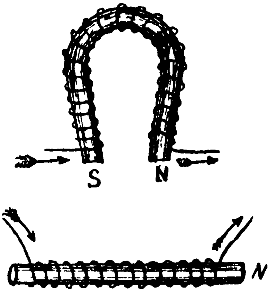

FIG. 6. ELECTRO-MAGNETS.

11. **How to make a Permanent Magnet.** A bar of hardened steel may be magnetised by stroking it from end to end, on all sides, with one pole of a strong permanent magnet. *The stroking must be always in the same direction, not backwards and forwards.* The end of the piece of steel last touched by the magnet will be of opposite polarity to the pole of the magnet which is used to stroke it. Thus supposing, (Fig. 7) the bar of steel had one end marked to distinguish it from the other, and that the steel were stroked from the unmarked to the marked end with the S. pole of the magnet, then the marked end

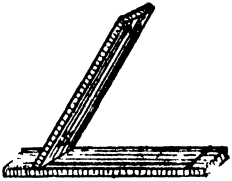

FIG 7. MAGNETISING A BAR OF STEEL.

would become a N. pole. A better way is to place the bar in a coil of covered copper wire round which a strong current of electricity is "passing," leaving it there a few minutes, and meanwhile tapping it sharply on the ends with a light hammer (Figs. 4 and 6). On taking the steel bar out of the coil, it will be found to be permanently magnetised.

The end of the bar which will be N. depends upon the direction in which the current is "flowing" round the coil, as viewed from the end. (See § 88.)

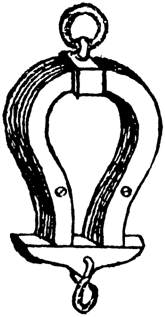

FIG. 8. COMPOUND MAGNET.

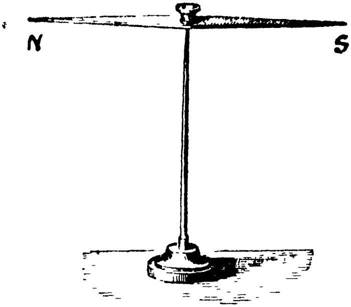

FIG. 9. MAGNETIC NEEDLE.

A still better way is to stroke the steel from the middle to one end on one of the poles of a strong electro-magnet, say thirty times on each side and edge; and then from the middle to the *other* end on the *other* pole of the magnet, thirty times on each side and edge.

The reason why steel must be hardened before being magnetised will be understood by the student when he has read as far as § 30.

12. Compound Magnets. Compound magnets are made by clamping together thin pieces of steel which have been separately magnetised. Fig. 8 represents a compound horseshoe magnet. A solid piece of steel cannot be strongly magnetised through and through, as may be proved by magnetising a steel bar, and afterwards immersing it in strong nitric acid. The acid will in time eat away the outer skin, and the steel bar when tested will be found to have lost a good deal of, if not all its magnetism.

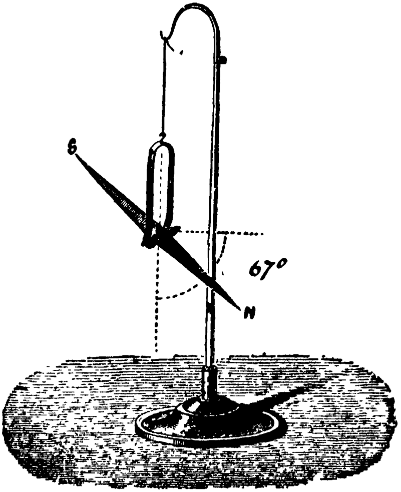

FIG. 10. DIP NEEDLE.

In order to get as much surface as possible with a given weight of steel, solid permanent magnets are nearly always made of flat ▭, instead of round ○ or square ◻ steel. It is for this reason also—the amount of magnetised surface

—that a compound magnet is so much more powerful than a solid magnet of the same shape and size.

13. **Horizontal Magnetic Needle.** As has been said before, when a magnet is suspended, so as to be free to turn, its poles will point N. and S. A magnetic needle (Fig. 9) is a magnet specially constructed for observing this effect. It consists of a piece of thin sheet steel which has been hardened and magnetised, and provided with a brass or agate centre cup, to enable it to be poised upon a fine hardened steel point, such as the point of a needle. The magnetic needle will move freely round upon its pivot, but if left to itself, will always come to rest with its poles pointing nearly true N. and S.

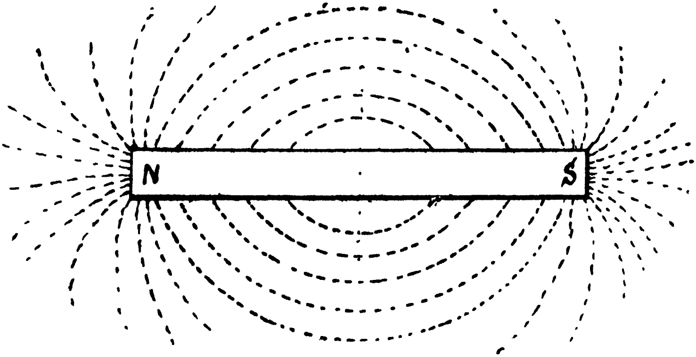

FIG. 11. MAGNETIC FIELD OF A BAR MAGNET.

14. **Dip Needle.** Another form of magnetic needle is shown in Fig. 10. The needle itself is very similar to the one just described, but it is so pivoted and suspended

that it can turn in any direction, right or left, up or down. This needle is called a *vertical* or *dip needle*, to distinguish it from the *horizontal needle* described in the preceding paragraph.

15. **Magnetic Attraction and Repulsion.** If the N. pole of a magnet be brought near to the N. pole of a horizontal magnetic needle, the needle will turn away from the magnet. Such will also be the case if the S. pole of the magnet be presented to the S. pole of the needle. But if the N. pole of the magnet be brought up to the S. pole of the needle, or the S. pole of the magnet to the N. pole of the needle, the needle will turn towards the magnet. If a piece of unmagnetised iron or steel be presented to either pole of the needle, attraction will result in both cases (§ 28). It is thus possible to tell by means of a magnetic needle whether a piece of steel is magnetised or not.

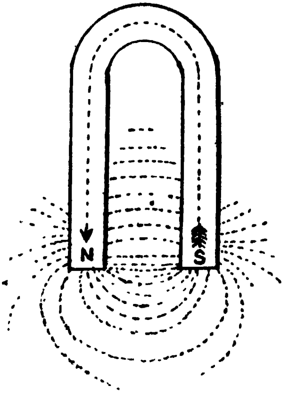

FIG. 12. MAGNETIC FIELD OF A HORSESHOE MAGNET.

16. **First Law of Magnetism.** The facts stated in the preceding paragraph are summed up by saying that: *Like magnetic poles repel, unlike magnetic poles attract.*

17. **Lines of Magnetic Force.** The power which a magnet possesses of picking up small pieces of iron, and of attracting or repelling the poles of another magnet,

and of pointing N. and S., depends on the existence of invisible *lines of magnetic force*, which curve through the air from one pole to the other (Figs. 11, 12).

18. **Magnetic Figures.** Lay a magnet flat down on the table, take a sheet of glass having one side covered with white paper, lay the glass on the magnet with the paper downwards, and sprinkle iron filings from a pepper-box evenly all over, gently tapping the glass meanwhile. The filings will arrange themselves along the lines of force and give us what is called a *magnetic figure.* Fig. 13 represents the magnetic figure due to a bar magnet.

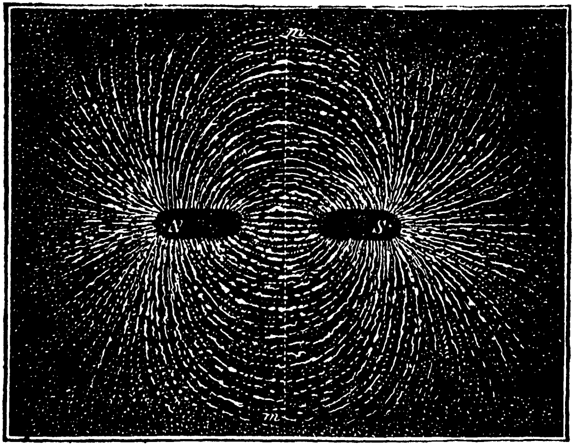

Fig. 13. Magnetic Figure given by a Bar Magnet.

19. **Magnetic Figures illustrating Attraction and Repulsion.** It has been seen that two N. or two S. poles repel each other, while a N. and a S. pole will attract each

other. If two bar magnets be laid on the table in line, separated by a distance of, say, two inches, with their two N. or two S. poles facing; by means of our sheet of glass and iron filings, we shall get a magnetic figure similar to the bottom one in Fig. 14, which gives one a very good idea of the repulsion which is taking place between the lines of force of one pole and those of the other pole. If, on the other hand, we place the N. pole of one magnet opposite the S. pole of the other, we shall get a figure in which the lines of force will be continuous from pole to pole, clearly denoting the attraction which is taking place between them. Such a figure is shown in the top half of Fig. 14.

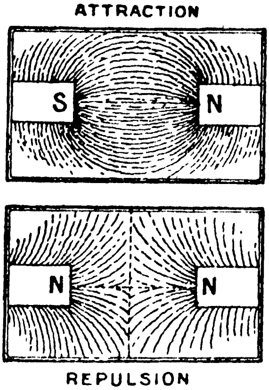

FIG. 14. MAGNETIC FIGURES ILLUSTRATING ATTRACTION AND REPULSION.

20. **Magnetic Field.** The air space surrounding a magnet is filled with these invisible lines of force, and is called the *magnetic field* of the magnet. Any space filled with magnetic lines, whether they be due to a magnet or to an electric current in a wire (§ 71), is called a magnetic field.

21. **Direction along Lines of Force.** Besides going through the air, the lines of force due to a magnet are supposed to pass through the substance of the magnet itself, from pole to pole. Just as we speak of going up or down a river or railway, so we imagine a positive (+) and a

negative (—) direction along these lines of force. The + direction along a line of force is from the N. to the S. pole of a magnet through the air, and from the S. to the N. pole through the magnet itself (§ 24). *The lines of force themselves, when once set up, do not move*, though we frequently speak of them as running in certain directions, just as we say that a road runs in a certain direction.

22. **There cannot be a Magnet with but One Pole.** If a bar magnet be broken in half, each piece will be found to act as a perfect magnet, and besides, each half will be practically as strong as the original whole piece. No matter how many parts we break a magnet into, each will be found to be a complete magnet by itself, having a N. and a S. pole. To prove this: Take a piece of steel wire six inches long and about one-eighth of an inch in diameter. With a smooth file cut three notches, one in the middle, and one an inch and a half from each end. This will mark out the piece of steel wire into four equal parts. Harden and magnetise the wire (§§ 3, 11), then, as might have been expected, if dipped into iron filings the filings will adhere to the ends and to the ends only. Now sever the magnet in the middle (this may be easily

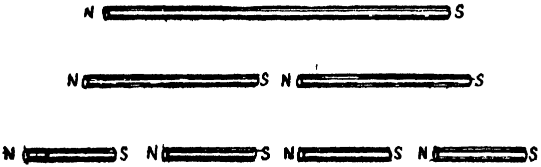

FIG. 15. EFFECT OF BREAKING A MAGNET.

done because of the notch); the two halves will attract filings at both ends. If we break each half, we shall have four distinct magnets. It will be noticed by the figure, that wherever we break the magnet, we get a N. pole on one side and a S. pole on the other. This may be proved by testing the broken pieces with a magnetic needle immediately after breaking them (§ 15).

23. **Magnetic Axis and Equator of a Magnet.** An imaginary straight line joining the two poles of a bar magnet is called its *magnetic axis.* The magnetic axis of a horseshoe magnet is an imaginary line joining the two poles, and running through the substance of the magnet. The *magnetic equator* of a magnet is an imaginary line drawn at right angles to its axis, and midway between the two poles. Fig. 16 represents the magnetic axis and equator of a bar magnet, and Fig. 12 the magnetic axis of a horseshoe magnet.

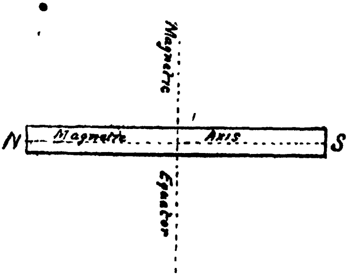

Fig. 16. Magnetic Axis and Equator of a Bar Magnet.

24. **Free Magnetism.** A line of force has no ends ; it forms a complete curve, whose shape depends upon circumstances. The lines of force issuing in all directions from the N. pole of a bar magnet curve through the air to the S. pole, and then through the substance of the magnet itself back to the N. pole, thus completing their *circuits.* In the figures on pp. 4, 8, 9, and 10, some of the

lines of force appear to terminate in the air, but that is not really the case, as we have just remarked. Where lines of force pass from the substance of a magnet into the air, we have what is called *free magnetism,* because it is only at such parts that small pieces of iron will adhere to the magnet. Take a bar magnet for instance: we find that when dipped into tacks, the tacks adhere only at the two ends or poles, *i.e.,* where the lines of force pass from the magnet to the air; and yet the magnet is strongly magnetised throughout its entire length, as can be proved by breaking it into pieces (§ 22).

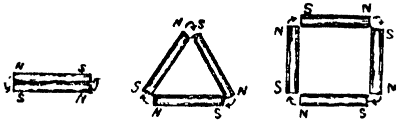

FIG. 17. MAGNETS COMPLETING THEIR CIRCUITS THROUGH THEMSELVES.

25. Internal and External Field of a Magnet. The portions of the lines passing through the substance of the magnet constitute its *internal field,* and the other portions passing outside, from the N. to the S. pole, form the *external field.*

26. Magnetic Circuit. The lines of force of a magnet, in completing their circuits from the N. to the S. pole, will prefer to pass through iron or steel rather than through the air, if the opportunity presents itself; or will pass through the substance of a neighbouring magnet, provided this other magnet is so disposed that its internal lines are in the same direction as the external lines of the first magnet. It is therefore possible, as shown in Figs. 17 and 22, to so arrange two or more magnets that their magnetic circuits are completed through themselves, only a few lines passing through the air: there is consequently very little free magnetism. By *magnetic circuit* of a magnet we mean the whole path of its lines of force.

27. **Law of Lines of Force.** *Neighbouring lines of force tend to turn themselves so that they lie parallel with one another, and in the same direction.* As a consequence of this, if a magnetic needle or any magnetised scrap of iron or steel, no matter how small, be placed in a magnetic field, such as between the poles of a horseshoe magnet, it will turn so that its own internal lines are parallel with, and in the same direction as, the lines of force of the field. The N. pole of the needle will then point in the + direction along the field. Before passing on, the student should be quite sure that he thoroughly grasps the meaning of this paragraph.

28. **Experiments with a Tube of Steel Filings.** Get a glass tube, say ten inches long and five-eighths of an inch internal diameter. Cork up one end, and fill the tube lightly with steel filings, and cork up the other end. The filings should not be jammed into the tube, and the corks should be as short as possible. If the tube be presented to a horizontal magnetic needle, we shall find that either end of the tube attracts either end of the needle, which proves that the tube of filings, as a whole, is unmagnetised (§ 15).

Next, place the tube within a coil of covered wire, and send a current of electricity from a battery (§ 66) round the coil for two or three minutes, so as to magnetise the filings in the tube, meanwhile giving the tube a few gentle taps. Now withdraw it carefully from the coil, taking care not to shake it, and it will be found that the tube acts just like a magnet; one end repelling the N. pole of the magnetic needle, and the other end attracting it. If the tube be placed in the stirrup shown in Fig. 3, one end will point N. and the other S. Now shake the tube vigorously, so as to thoroughly disarrange the filings, and it will be found that all its magnetism has disappeared.

29. **Molecular Theory of Magnetism.** What magnetism really is it is impossible as yet exactly to say, but it is convenient to look upon every particle of iron and steel as being a perfect magnet with a N. and a S. pole. Imagine what would be the effect of jumbling together a lot of small magnets: each little N. pole would unite itself with the S. pole of a neighbouring magnet, and *vice versâ,* and there would be very little free magnetism. The molecules or particles of a piece of unmagnetised iron or steel may be considered to be in this confused condition, each little magnetised molecule completing its magnetic circuit through neighbouring molecules. The piece of iron or steel as a whole, therefore, exhibits no free magnetism.

When we magnetise a piece of iron or steel, *i.e.*, when we so arrange its already magnetised molecules as to give us free magnetism, we do so by causing the lines of force due to a magnet or to an electric current in a wire, (§ 69) to pass through the substance of the piece of steel or iron magnetised. The effect of this (§ 27) is to cause little magnetised molecules to set themselves in lines, and so that their own internal lines may the same direction as the lines of force which we passing through them.

his state of things is represented at the bottom of 18. Except at the ends of the bar, all the N. poles ie opposite S. poles, and we get no free magnetism; at one end of the bar we have a row of free N. poles, at the other a row of free S. poles, and there, con-

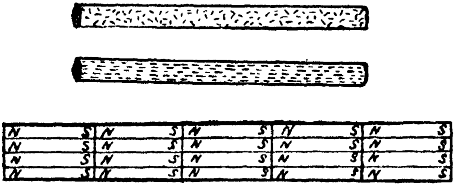

FIG. 18. Illustrating the Unmagnetised and Magnetised Condition of a Bar of Steel.

quently, we get free magnetism. The top and middle Fig. 18 represent a bar of steel in the unmagnetised d magnetised condition respectively.

30. **Difference between the Magnetic behaviour of Iron and eel.** The molecules of a piece of steel may be supposed be much more closely packed together than the molecules of soft iron. If the steel be hardened, its molecules come still more closely packed together. This exains two facts: (1) If a bar of hardened steel and ar of soft iron be placed in turn within a coil of wire und which electricity is "flowing," the iron will be

much more strongly magnetised for the time being than the steel. (2) When taken from the coil, the soft iron will be found to have lost all its magnetism; but the steel will be permanently magnetised. The molecules of the iron and steel are alike magnetised, and at first are in the jumbled-up condition in which no free magnetism is apparent. When placed in turn within the coil of wire, the lines of force due to the current in the coil (§ 84) have much less difficulty in turning the molecules of the soft iron in line, than the molecules of the hardened steel, because the latter are so much more closely packed together. Consequently, while the electricity is flowing, the iron is the most strongly magnetised. When the current is stopped, or when the bars are taken out of the coil, there is nothing to keep the molecules of the soft iron in line, and as they are not closely packed together, and prefer to complete their magnetic circuits through themselves rather than through the air, they return to their previous jumbled-up condition, and the iron loses its free magnetism. On the other hand, the molecules of hardened steel having been more or less turned in line, remain so, because—being so closely packed together—they are less free to move among themselves than the molecules of soft iron. *This explains why it is that hardened steel may be permanently magnetised;* and also it will be clear why tapping a bar of steel assists its magnetisation (§ 11).

31. **What happens when a Piece of Steel or Iron is Magnetised.** The student will now clearly perceive that when we magnetise iron or steel, we do not impart

magnetism to it from another body (such as a magnet or a wire carrying electricity), but merely use the lines of force of that other body for the purpose of turning the already magnetised molecules into line.

32. **Effect of Vibration and Heat on Magnetism.** If a permanent magnet is subjected to rough usage, such as being dropped on the floor or hit with a hammer, it will lose more or less of its free magnetism, for the vibration among its molecules allows them to jumble themselves up. When a body is heated, its molecules are set into rapid motion among themselves ; consequently if a steel magnet be heated to a red heat, it will be found on cooling to have lost all its free magnetism, its molecules having turned so as to complete their magnetic circuits among themselves.

33. **Magnetic Induction.** We have seen that when lines of force from an independent source are made to pass through a piece of steel or iron, their effect is to turn the molecules of the steel or iron into line, so that it exhibits free magnetism. In that condition the steel or iron is said to be *polarised.*

Experiment (Fig. 19). Tie together a strip of soft iron and a bar magnet, with a piece of cardboard or wood interposed, the iron being about the same size as the magnet. The iron will be found to be magnetised, as may be shown by dipping it into a heap of iron filings ; in other words, the soft iron is magnetised by the *induction* of the neighbouring magnet. If the magnet be removed, the iron will lose its magnetism. What happens is this : the majority of the lines of force of the magnet, in completing their circuit, prefer to pass through the neighbouring piece of iron rather than through the air. In so doing they polarise the soft iron, and cause it to exhibit free magnetism.

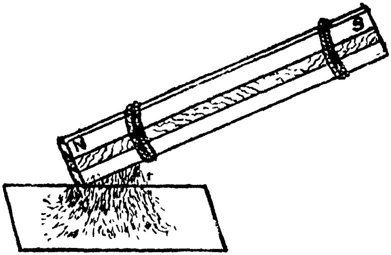

FIG. 19. MAGNETIC INDUCTION.

34. **Induction precedes Attraction.** When a magnet attracts a piece of iron, it first of all magnetises it by induction. Let S N (Fig. 20) represent the piece of iron.

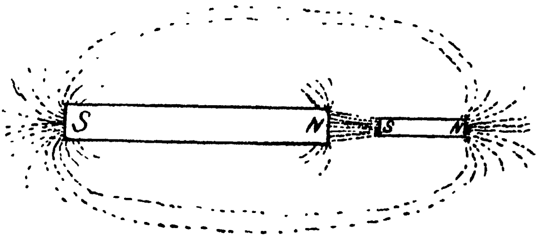

FIG. 20. MAGNETIC INDUCTION. MAGNET INDUCING MAGNETISM IN A PIECE OF IRON BEFORE ATTRACTING IT.

As the north pole N. of the magnet is brought up to the iron, its lines of force pass through the iron and polarise it; and, from what was said in § 27, it is evident that the piece of iron will be so polarised that its end nearest the pole of the magnet will be of opposite polarity, and attraction will, as a consequence, take place between the N. and S. poles.

35. **Permanent Magnets and their Keepers.** When not in use, permanent magnets should be so arranged that their lines are allowed to complete their magnetic circuit through soft iron or through another magnet rather than through the air ; for if not, they will slowly but surely lose their free magnetism. For this reason bar magnets are generally supplied in pairs, provided with two pieces of soft iron called *keepers*, and arranged as shown in Fig. 21. They should not lie close together side by side, but should have a small piece of wood placed between them. A horseshoe magnet is, for a similar reason, provided with a keeper (Fig. 5), or two horseshoe magnets of the same size will act as keepers the one to the other (Fig. 22) (§ 26).

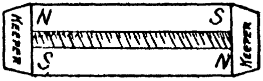

FIG. 21.

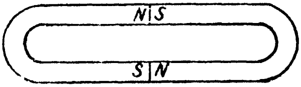

FIG. 22.

Lines of force pass through iron or steel much more easily than through air, and this is the first reason why keepers should be used, for if the lines of force are not provided with an easy path, there is less compulsion for the molecules of the magnet to remain in their polarised positions. Furthermore, the neighbouring magnets in

Figs. 21 and 22 react on one another, and the keepers (in Fig. 21) becoming polarised, react on the magnets, all in such a manner that everything is favourable for keeping the molecules of the magnets in their polarised positions.

36. **Magnetism of the Earth.** In §§ 5, 7, and 13, it is stated that if a magnet be freely suspended, it will come to rest so that its poles point towards the poles of the Earth. The Earth acts as if it were a huge magnet, having its *magnetic poles* comparatively near to, but not coincident with, its *geographical poles.* The lines of force forming the Earth's external field curve round over the surface of the Earth from pole to pole, and act on a freely

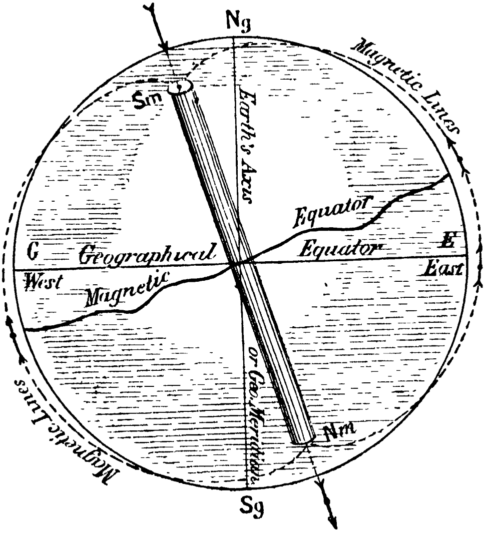

FIG. 23. THE EARTH AS A MAGNET.

suspended magnet in such a manner that the magnet turns until it lays as nearly as possible along one of these lines (see § 27). This is the position which a dip needle takes up (§§ 14 and 40).

In Fig. 23, the line N_g—S_g represents the axis on which the Earth turns, or it may be considered as a geographical meridian passing over the Earth's surface. N_g and S_g represent the N. and S. geographical poles. S_m N_m is an imaginary bar magnet passing up through the centre of the Earth, S_m being the Earth's S. magnetic pole, and N_m its N. magnetic pole. Just as the geographical equator G E is an imaginary belt passing round the Earth midway between its geographical poles; so the magnetic equator is a line encircling the Earth, midway between its magnetic poles, and passing through places where there is no dip, *i.e.*, where the dip needle lies perfectly horizontal (§§ 39 and 40). The arrows denote different positions of the dip needle, the arrowhead being the N. pole.

37. **Magnetic Polarity of the Earth.** As we call the pole of a magnet which points towards the N. geographical pole of the Earth, its N. pole; to be correct, we must consider the magnetic pole in the northern hemisphere as being S. Similarly, the magnetic pole in the southern hemisphere must be N.

38. **Geographical and Magnetic Meridians. Declination.** An imaginary straight line passing through any place on the Earth's surface, and running in the direction of the N. and S. geographical poles, is called the *geographical meridian* of the place. An imaginary straight line passing through any place, and running in the direction of

the Earth's N. and S. magnetic poles, is called the *magnetic meridian* of the place. The angle between the magnetic and geographical meridians is called the *declination,* or *declination angle,* and denotes how much away from true N. the compass needle points (Fig. 24). The declination is constantly varying; at the present time its value is about 17° W., which means that when the compass needle comes to rest, true N. is 17° to eastward.

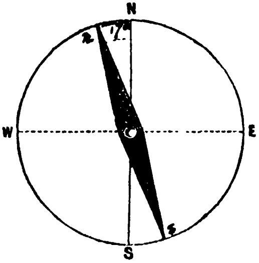

FIG. 24. DECLINATION.

39. **Difference in the Action of the Horizontal and Dip Needles.** At the equator, the lines of force due to the Earth are horizontal, but become more and more vertical as we approach either magnetic pole. A horizontal needle can only indicate the vertical plane in which these lines of force

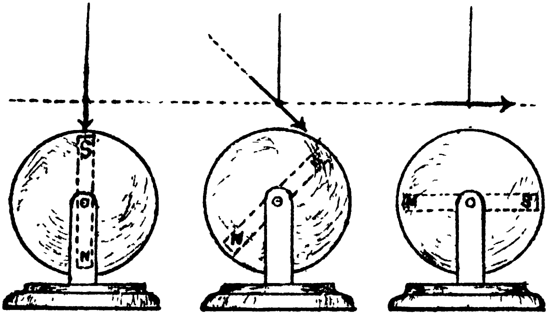

FIG. 25. ACTION OF THE DIP NEEDLE AT VARIOUS PARTS OF THE EARTH.

lie: a dip needle, being free to turn in any direction, actually lays itself along these lines of force (§ 27). At the magnetic equator, the dip needle would be horizontal, but as we approached either magnetic pole, it would dip down more and more, till at the poles it would stand quite vertical. This action will be better understood from Fig. 25. The left-hand figure shows

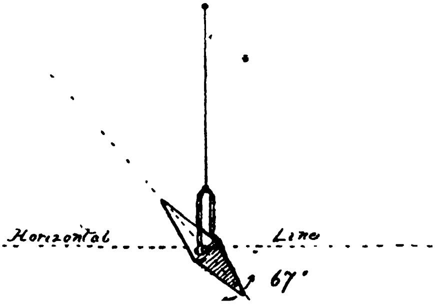

FIG. 26. VALUE OF THE INCLINATION OR DIP AT LONDON.

the position taken up by the dip needle at the S. magnetic pole, the arrowhead being the N. pole of the needle. The middle figure indicates the position of the dip needle at London, and the right-hand figure shows its position anywhere on the magnetic equator.

40. **Inclination or Dip.** The angle which the dip needle makes with the horizontal at any place on the Earth's surface, is called the *inclination* or *dip* at that place. Thus,

at the equator the dip is hardly anything, at London it is 67°, and at the magnetic N. or S. pole it would be 90° (Figs. 10, 25, and 26). In the northern hemisphere the N. pole dips down; in the southern hemisphere, the S. pole.

41. **Magnetisation of Soft Iron by the Earth.** If a rod of soft iron, such as a poker, be fixed in the position which a dip needle would take up, some of the lines of force of the Earth will run through the poker, and tend to polarise it. This may be shown to actually be the case if the poker is struck a few times with a mallet, to assist the polarisation of its molecules,—while in position, of course,—and its ends tested by means of a small compass. The lower end will be found to be N., and the upper end S., if the experiment is performed in the northern hemisphere.

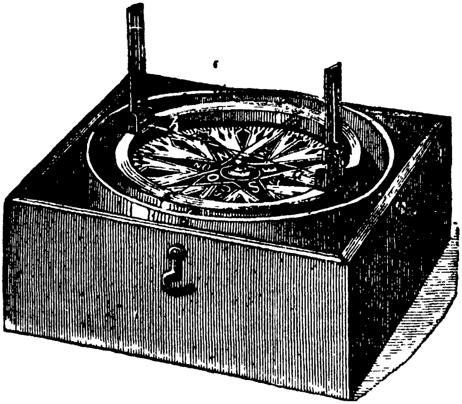

FIG. 27. MARINER'S COMPASS.

42. **Mariner's Compass.** The magnetic needle is indispensable in navigation, as thereby it is possible to at once ascertain the direction of the Earth's poles, and, consequently, to direct the vessel's course by the chart. In a toy compass the needle is pivoted above the card on which the various *points of the compass* are marked. To ascertain any particular direction, it is necessary to wait till the needle comes to rest, and then gently twist the case and card round until the N. point on the card is directly underneath the N. pole of the needle. In the *mariner's compass* the needle is rigidly fixed to the underside of the card, so that the needle and card swing round together, and the N. point on the card is always pointing in the direction of N. The compass is fixed within its box on *gimbal bearings*, so that the card will always be level, no matter how much the instrument be tilted by the pitching and rolling of the ship (Fig. 27).

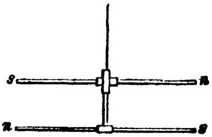

Fig. 28. Astatic Needle.

43. **Astatic Needles.** If two magnetic needles of equal size and strength be rigidly fixed one above the other, with their unlike poles opposite, such an arrangement will clearly be independent of the Earth's magnetism, and will come to rest in any desired position when suspended. Two needles so arranged are called *astatic needles* or an *astatic needle* (Fig. 28). Astatic needles are used in an instrument called the astatic galvanometer (§ 93).

END OF PART I.

QUESTIONS.

PART I.—MAGNETISM.

In answering these questions, give sketches wherever possible.

1. What is a magnet?

2. What is lodestone?

3. How would you harden a piece of steel?

4. Given a piece of lodestone and a sewing-needle, describe how you would magnetise the latter by means of the former.

5. If you had two pieces of steel, alike in shape and size, one of which was magnetised and the other not; in how many ways could you find out which was the magnetised piece? Explain each method.

6. Explain the difference between an artificial and a natural magnet.

7. Explain the difference between a permanent and an electro-magnet.

8. What are the poles of a magnet?

9. Has a bar magnet any advantage over a horseshoe magnet?

10. Given a bar of hardened steel, the ends of which are marked A and B, how would you magnetise it, by using the S. pole of a bar magnet, so that the B end of the bar became a S. pole?

11. How is a compound horseshoe magnet constructed?

12. Give reasons for the greater strength of a com-

pound magnet as compared with a solid magnet of the same shape and size.

13. What is a horizontal magnetic needle?

14. What is a dip needle?

15. Say what you know about magnetic attraction and repulsion.

16. If a piece of steel attracts the N. pole of a magnetic needle, is that a proof that the steel is magnetised? Give reasons for your answer.

17. What are lines of force?

18. Give a sketch of the magnetic figures due to a bar magnet and to a horseshoe magnet.

19. What is a magnetic field?

20. What is the + direction along the lines of force in the interior of a bar magnet?

21. Explain fully why a magnet must always have two poles.

22. Given a bar magnet, N. S., explain with sketches what would be the result of breaking it into five pieces.

23. If a horseshoe magnet were broken in two at its middle, what would be the result?

24. Define "magnetic axis" and "magnetic equator" of a magnet.

25. What is free magnetism?

26. Explain the difference between the internal and external field of a magnet.

27. Say what you know regarding the behaviour of lines of force among themselves.

28. What would be the effect of suspending a small bar magnet in a magnetic field?

29. Explain the molecular theory of magnetism.

30. Give a full account of any experiments you know of which tend to uphold the above theory.

31. What is meant by saying that so many small magnets can complete their magnetic circuits among themselves?

32. Give two sketches, with explanation, illustrating the supposed condition of the interior of a bar of hardened steel—(1) in an unmagnetised condition; (2) when magnetised.

33. Place a bar of hardened steel and a bar of soft iron in turn within a coil of covered wire round which electricity is flowing. While within the coil, each will be magnetised; the iron will, however, be more strongly magnetised than the steel. After being taken out of the coil, the steel will still be magnetised, but the iron will have lost all its magnetism. Give full reasons for these effects.

34. Why must steel be hardened before being magnetised?

35. Explain clearly why, if we rub a knitting-needle from end to end with one pole of a bar magnet, the needle becomes magnetised.

36. What would be the effect of making a bar magnet red-hot?

37. What is magnetic induction?

38. What is meant when we say that a piece of iron is polarised?

39. If the pole of a magnet be approached slowly to a tack lying on the table, the tack will at last jump

up to the magnet. Explain clearly what happens to the molecules of the tack.

40. Why should permanent magnets be always provided with keepers?

41. Say what you know about the magnetism of the Earth.

42. What is the difference between a geographical and a magnetic meridian?

43. Why does the N. pole of a magnetic needle point towards the N. geographical pole of the Earth?

44. Why does the N. pole of a dip needle dip downwards in Great Britain? How would it act—(1) in Abyssinia; (2) in New Zealand; (3) at the Earth's N. magnetic pole?

45. Define "declination" and "inclination."

46. Given a dip needle and a long bar of soft iron, say if you could render the latter magnetic without bringing it into contact with the needle. If so, how?

47. Explain the construction and use of the mariner's compass.

48. What are astatic needles?

In answering these questions, give sketches wherever possible.

PART II.

ELECTROKINETICS, OR ELECTRICITY IN MOTION.

44. **Electricity.** What electricity really is it is impossible to say, but for the present it is convenient to look upon it as a kind of invisible something which pervades all bodies. Electricians are able to keep electricity perfectly under control, and to use it for very many purposes; yet all the while they have no certain knowledge of what they are dealing with, except from its effects; so that, although we shall hereafter frequently speak of electricity as *flowing through a conductor*, or of a body as being *charged with electricity at rest*, the student must bear in mind that these are only convenient ways of explaining the various effects that are obtained.

45. **Theory of Electricity.** Think of all substances—the Earth and everything on it—as having a certain quantity of electricity upon them. So long as every body has its proper share of electricity, no electrical manifestation is observed; but directly we give a body more than its proper share, or, taking electricity from it, leave it with less than its proper share, then it is that we become aware of the effects of what we call electricity.

46. **Positive and Negative Electrification.** When a body has more than its proper share of electricity, it is said to

be in a state of *positive* (+) *electrification;* when it has less than its proper share, it is said to be in a state of *negative* (−) *electrification.*[1]

When two different substances, such as glass and silk, or sealing-wax and flannel, are rubbed together, + electrification is developed on one, and − electrification on the other. If two plates of different metal are placed side by side in a liquid which acts chemically on one of them more than on the other, the same thing is observed—viz., one of the metals will be in a state of +, and the other in a state of − electrification (§§ 52, 53, 99).

47. **Potential.** When a body is in a state of + electrification, it is said to be at a higher *potential* than the Earth, whose potential is taken as zero. When a body is in a state of − electrification, its potential is said to be lower than that of the Earth. To make this more clear, let us consider a number of men. So long as every man had the same amount of money there would be no rich or poor amongst them. But directly one man got more money than any of the others, he would become rich as compared with them. On the other hand, if one of them parted with some of his share, he would become poor as compared with the rest.

While every man has an equal amount of money, the idea of riches or poverty does not exist. When every body has its proper share of electricity, electricity is not apparent. When a man gets more than the average share of money, he becomes rich—his value is increased. When a body has a surplus of electricity, its potential is raised above the average, *i.e.*, above the potential of the Earth. When a man parts with some of his money, he becomes poor—his value is decreased. When a body has less than its proper share of electricity, its potential is lowered beneath that of the Earth. Just as we measure the heights of mountains or the depths of mines from the sea level, so we take the potential of the Earth as zero. A body whose potential is above that of the Earth is said to be at a + potential, while a body whose potential is less than that of the Earth is said to be at a − potential. Though two bodies be at a + potential, it is clear that one may be at a higher potential than the other. Similarly, two bodies may be at a − potential, yet there may be a difference of potential between them.

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[1] The signs + and − when used here, signify positive and negative, *not* plus and minus.

48. **"Flow" of Electricity.** Whenever any two bodies are at different potentials, electricity tends to "flow" from the body at the higher potential to the body at the lower potential. Or if a body be at a higher or lower potential than the Earth, electricity tends to "flow" between the two until the potentials are equalised.

49. **Insulators.** If there be a sufficiently great difference of potential, electricity will flow through anything, even air, as is the case with the lightning flash. When electricity is not at a high potential or pressure, there are some bodies which offer considerable resistance to its "passage" through them. With electricity at the low potential or pressure used in practical work, some substances offer such a comparatively high resistance, that practically they allow no electricity to flow through them. Such substances are called *insulators* or *non-conductors*.

50. **Conductors.** Bodies which allow electricity to "flow through" them without much difficulty, are called *conductors.* There is, however, no such thing as a perfect conductor, for every body offers more or less resistance to the "flow" of electricity. The difference between a conductor and an insulator is one of degree only, for whether a body will or will not allow electricity to "flow through" it, depends merely on the pressure of the electricity, *i.e.*, the difference of potentials of the bodies between which the electricity tends to flow.

51. **List of Conductors and Insulators.** Following is a list of bodies in their *order of conductivity:* those at the top of the list, the metals especially, offer very little resistance to the passage of electricity, and are therefore called conductors ; as we descend the list, the bodies increase in resistance, becoming worse conductors and better insulators ; those at the bottom offer extremely great resistance to the flow of electricity, and are therefore called insulators.

Good conductors .	Metals.
Fair conductors	Charcoal and coke.
	Carbon.
	Plumbago.
	Acid solutions.
	Sea water.
	Saline solutions.
	Metallic ores.
	Living vegetable substances.
	Moist earth.

Semi-conductors	Water. The body. Flame. Linen. Cotton. Dry wood. Marble.
Insulators	Slate. Oils. Porcelain. Dry leather. Dry paper. Silk. India-rubber. Gutta-percha. Ebonite. Mica. Jet. Sealing-wax. Sulphur. Resins. Amber. Paraffin wax. Shellac. Glass. Dry air.

52. Contact causes Electrification. The mere fact of bringing unlike surfaces into contact is sufficient to develop + electrification on one surface, and — electrification on the other. Thus, for instance, if two different metals, such as silver and copper (a half-crown and a penny), be laid one upon the other, one will become positively electrified and the other negatively electrified, but it requires a very delicate electroscope (§ 112) to detect the potential difference between the two. If a piece of zinc be substituted for the silver, the same effect will occur.

53. **Simple cell.** It is not necessary for the two metals to be in actual contact with each other. If they be put side by side into some liquid which will act on one of them more than on the other, a much greater potential difference will be set up between the two. Thus, if a plate of zinc and a plate of copper, each with a piece of copper wire soldered to it, be stood side by side—without touching—in a glass vessel containing one part of sulphuric acid mixed with about ten parts of water, the wire connected with the copper plate will be at a + potential, and the wire in connection with the zinc plate will be at a — potential. If the wires be joined together, electricity will flow through them in the form of a "*current*," from the copper to the zinc. It is convenient to suppose that the electricity starts from the surface of the zinc plate, passes through the liquid to the copper plate, and thence through the connecting wires back again to the zinc.

54. **Action of Simple cell.** A constant potential difference (abbreviated P.D.) is kept up between the zinc and copper plates, due, firstly, to the contact of two different metals, *i.e.*, where the copper wire is fastened

to the zinc plate, and secondly and principally to the chemical action of the *exciting fluid* upon the zinc. The chemical action of the sulphuric acid on the zinc is as follows:—Sulphuric acid is made up of three elements, sulphur (S.), oxygen (O.), and hydrogen (H.), united in the proportions of SO_4H_2, *i.e.*, 1 of sulphur, 4 of oxygen, and 2 of hydrogen. The SO_4 part of the sulphuric acid (SO_4H_2) much prefers to unite itself with zinc (Zn.) than with hydrogen (H.), if the wires between the zinc and copper plates be joined: consequently, the Zn. dissolves into the acid, forming zinc sulphate ($SO_4Zn.$), and H. is set free in the form of a gas, which passes through the liquid, and plasters itself upon the surface of the copper plate.

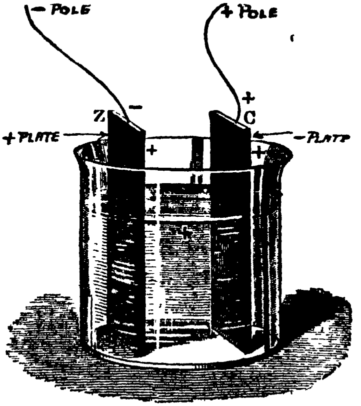

FIG. 29. SIMPLE CELL.

The chemical action we have just described may be expressed as follows:—

$$Zn. + SO_4H_2 = SO_4Zn + H_2.$$

55. **Polarisation.** The deposition of H. gas upon the surface of the copper plate weakens the current: firstly, because the electricity has to pass through a film of H., which offers considerable resistance; and secondly, because

the copper plate at last becomes so covered with hydrogen bubbles, as to be practically a hydrogen plate. Now the effect of dipping a hydrogen and a zinc plate together into dilute sulphuric acid, would be to set up a current from the H. to the Zn. plate inside the cell, and from the Zn. to the H. outside; this current would, therefore, work against the Zn. to Cu.[1] current, and so weaken it. When the action of a cell is stopped in this way, the cell is said to have become *polarised.* If the H. bubbles could only be prevented from sticking to the Cu. plate, the simple cell would give a current so long as there was any zinc left, and any sulphuric acid to act upon it.

56. **+ and — Plates of a cell.** In a simple cell, other materials besides copper may be used with the zinc plate, *e.g.*, platinum, silver, or carbon, or in fact any conducting substance which will not be acted upon by the sulphuric acid. A cell is a kind of chemical furnace wherein zinc (the fuel) is dissolved (or burnt) in acid, and an electric current developed. The zinc is therefore called the + *plate* or *element* of a cell, because, as we saw in § 53, it is from the surface of the zinc that the current is supposed to start, passing through the exciting liquid to the other plate, and thence through the wires outside the cell back again to the zinc. This other plate, the — *plate* or *element* of the cell, which may be of silver, platinum, carbon, copper, etc., is not acted upon by the liquid, and may be regarded simply as a kind of conducting hand which is dipped into the cell, collecting the electricity therefrom, and leading it away to the outer circuit.

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[1] Copper, Latin *Cuprum;* abbreviated Cu.

57. **+ and — Poles of a cell.** The electricity starts on its outside journey from the — plate of the cell, passing through the wires to the + plate. The — plate is therefore called the + *pole* of the cell, and the + plate the — *pole.*

58. **Local Action.** In § 54 it was stated that the Zn. only dissolved into the acid when the + and — plates were joined by a wire outside the cell ; this unfortunately is only the case if pure zinc be used. Pure zinc, however, is very difficult to obtain, the zinc of commerce containing many impurities, such as small particles of coke (carbon), lead, tin, iron, etc. When the zinc plate is dipped into the cell, each minute particle of foreign matter with the zinc round it forms a little local cell, and the consequence of this is that the zinc is continually being eaten away, whether a current is taken from the cell or not. This eating away of the zinc when the cell is supposed to be at rest, is called *local action.*

59. **Amalgamation.** Local action may be prevented by thoroughly cleaning the surface of the zinc plate in dilute acid (*i.e.*, acid mixed with about 10 parts of water), and then applying mercury (quicksilver) by means of a piece of rag tied to a stick. The mercury will form a bright film or amalgam over the surface of the plate, which in this condition is said to be *amalgamated.* The zinc plates of cells are not always amalgamated, partly because some exciting fluids do not act so strongly on the zinc as others, and also because of the expense.

60. **Two-fluid cells.** Polarisation, and its weakening effect on the current, could be prevented in the simple cell if the H. bubbles were shaken or brushed off, as

soon as they formed on the copper plate, but to do so would not be practicable. In *two-fluid cells*, polarisation is prevented by surrounding the — plate with a liquid or solid which will absorb the H. bubbles.

This liquid is called the *depolarising fluid* of the cell, and is, in most cells, separated from the exciting fluid by a porous partition of unglazed earthenware, which allows H. and electricity to find their way through, but keeps the liquids separate. When a solid is used to absorb the H. gas, as in the Leclanché cell (§ 65), it is called the *depolariser*. There are many kinds of two-fluid cell, the principal of which will now be described.

61. **Daniell cell.** The Daniell cell is made in a variety of forms, but the principle of all is the same. The cell is generally divided into two parts by a porous partition, the zinc being in one half, surrounded by dilute sulphuric acid as in the simple cell; and the copper plate in the other half dipping into a saturated solution of sulphate of copper, *i.e.*, water in which as many as possible of the blue crystals of sulphate of copper are dissolved.

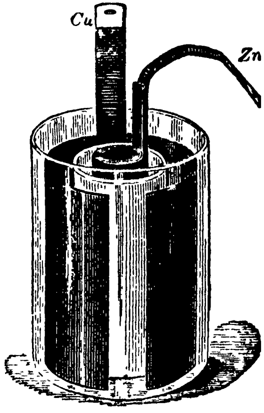


FIG. 30. DANIELL CELL.

Fig. 30 illustrates a form of Daniell cell. In the outer glass cell stands a cylinder of thin sheet copper immersed in the sulphate of copper solution, and surrounding a *porous pot* of unglazed earthenware containing a zinc cylinder and dilute sulphuric acid. Instead of the zinc cylinder, a rod or plate of zinc may be used. The chemical action of the cell is as follows: the zinc burning in the sulphuric acid, forms sulphate of zinc and sets hydrogen gas free. The hydrogen, passing through the porous partition, is attacked by the sulphate of copper ($SO_4Cu.$), and with the SO_4 part of it forms sulphuric acid (SO_4H_2), the liberated copper being deposited upon the surface of the copper plate instead of hydrogen gas.

The action is expressed as follows :—

Porous partition.

$Zn. + SO_4H_2$	$SO_4Cu.$
(Zinc cylinder or rod.) (Sulphuric acid.)	(Sulphate of copper.)
$SO_4Zn.$	$H + SO_4Cu.$
(Sulphate of zinc.)	(Hydrogen.) (Sulphate of cop.)
	$SO_4H_2 + Cu.$
	(Sulphuric acid.) (Copper deposited on copper plate.)

62. **Bunsen cell.** In the Bunsen cell, a carbon plate is used for the — element, immersed in the strongest nitric acid; the zinc plate as before being in dilute sulphuric acid. A porous pot contains the carbon plate and nitric acid, the zinc, which must be well amalgamated, being made in the form of a cylinder surrounding the porous pot, and standing in the outer cell. The nitric acid absorbs the hydrogen gas, so preventing it from reaching the carbon plate, and causing polarisation.

63. Bichromate cell. In the bichromate cell, the porous partition is dispensed with, a single fluid acting both as exciter and depolariser. Zinc and carbon are used, dipping side by side into a solution made as follows:—

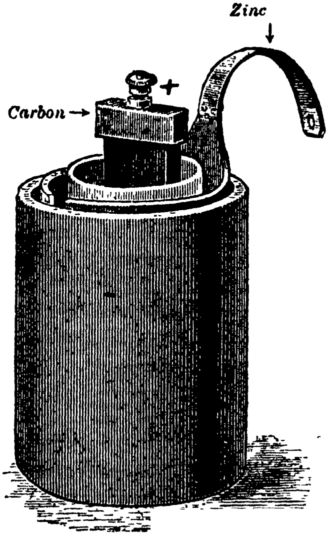


FIG. 31. BUNSEN CELL.

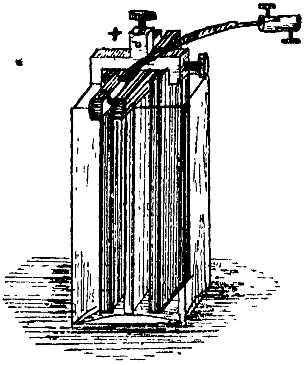


FIG. 32. BICHROMATE CELL.

Finely-powdered bichromate of potash	3 oz.
Boiling water	1 pint.

Stir with a glass rod, allow to cool, and then add gently, stirring all the while,

Sulphuric acid	3 oz.

The solution must be allowed to cool before being used.

The zinc and carbon plates are generally of the same size, one of the carbon plates, of which there are two, being strapped on either side of the zinc, separated from it by strips of wood, which have been previously soaked in boiling paraffin wax. The zinc in this cell requires to be well amalgamated, and must not be left in the solution for any length of time, or it will soon be eaten away.

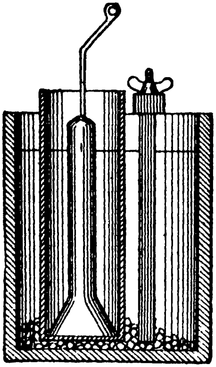


FIG. 33. FULLER CELL.

The plates or elements of the cell should not be placed in the solution until the cell is wanted for use; and should be taken out and rinsed in clean water, directly the cell is done with.

64. **Fuller cell.** The Fuller cell is much the same as the Bichromate cell, except that a porous pot is used to separate the exciting and depolarising solutions. In the outer earthenware or stoneware cell stands a carbon plate immersed in a solution made as follows:—

Chromic acid	3 oz.
Water	1 pint.

Stir till dissolved; then add gradually, with constant stirring,

Sulphuric acid	3 oz.

This solution must not be used till cold.

The zinc rod stands in the porous pot in a very weak solution of sulphuric acid. The zinc must be well amalgamated, and for this purpose it is cast with a foot, so that it will stand upright in the porous pot, and about 2 oz. of mercury are poured in so as to cover the bottom of the zinc. The porous pot should be soaked in boiling paraffin wax, leaving only a strip about half an inch wide down the side untouched. This prevents the too rapid mixing of the liquids, for when the chromic acid solution soaks through into the porous pot, it eats away the zinc very quickly. If the porous pot (which should be a dense one) be paraffined as directed, the cell may be left to itself without troubling to withdraw the zinc after use. Herein lies the advantage of the Fuller cell over the ordinary Bichromate cell, an advantage which enables it to be very extensively used in telegraphy, etc.

The above solution may be used in the Bichromate cell, and the solution mentioned in § 63 may be used in the Fuller cell.

65. Leclanché cell. This cell is very much used for electric bell and alarm work. It consists of a carbon plate in a porous pot, closely packed round with small lumps of broken carbon and black oxide of manganese, in equal proportions. This latter forms the solid *depolariser* of the cell. The porous pot stands in a glass jar containing a zinc rod, and an exciting solution made by dissolving crystals of sal am-

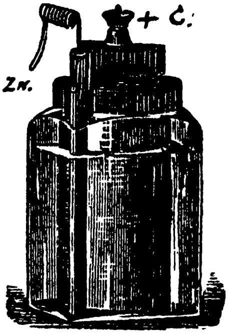
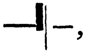


FIG. 34. LECLANCHÉ CELL.

moniac in water. This cell must only be used for intermittent work, if it be made to give a continuous current for any length of time (say half an hour), it will "run down" or polarise, but will recover itself after an interval of rest. It is not absolutely necessary for the zinc rod to be amalgamated.

66. **Cells in Series and Parallel.** A *battery* of cells is generally formed by connecting the zinc of one cell with the carbon or copper of the next, and so on to the end; the free carbon or copper plate at one end, and the free zinc at the other end, forming respectively the + and — terminals, or poles of the battery. Electricians represent a cell by the symbol , the short thick line representing the zinc, the long thin one the carbon or copper. Cells so arranged are said to be *in series.*

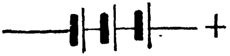


FIG. 35. THREE CELLS "IN SERIES."

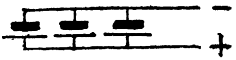


FIG. 36. THREE CELLS "IN PARALLEL."

In some cases, as when the battery has to work through a very low outside resistance, and a strong current is wanted, cells are joined *in parallel,* of which there are any number of methods. The simplest arrangement is to join all the zincs of the cells together to form one pole, and all the carbons to form the other pole.

Fig. 35 represents three cells in "series," and Fig. 36 three cells in "simple parallel."

Another parallel arrangement of cells is shown in

Figs. 38 and 39, which may be described as *three parallel rows of four cells in series.*

67. **Electromotive Force of cells.** Principally owing to the chemical action of the exciting fluid on the zinc, the P.D. between the poles of the cell is kept up constantly, so that a steady "current" of electricity flows along the outside wire when they are joined together. The total P.D. of a cell is called its **Electromotive Force** (written E.M.F.), and is measured in *volts.* The E.M.F. of a cell depends upon the materials of which it is composed, and consequently varies in different cells, as will be seen from the following table:—

	E.M.F. in Volts (approximate).
Fuller	2·14
Bichromate	2·00
Bunsen	1·96
Leclanché	1·60
Daniell	1·00

67*a*. **Use of Batteries and Dynamos.** Batteries are used to furnish the current required in working telegraphs and telephones, electric signals, alarms, and bells, etc. When strong currents are required, as in electric lighting, and in the working of electric railways, etc., the currents are obtained from *dynamos.* A dynamo is a machine in which coils of wire are rapidly revolved in the magnetic field of powerful magnets, this causing currents to be *induced* in the coils of wire (§ 97*a*).[1]

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[1] See the Author's "Practical Electrical Notes," published by Spon.

68. **The Circuit.** The circuit is the conducting path through which the electricity "flows." Every circuit may be divided into three parts:—

(*a*) The source of electricity, *i.e.*, the battery or dynamo (§ 97*c*).

(*b*) The apparatus through which the electricity flows.

(*c*) The wires connecting the various parts.

69. **Properties of a current.** A current of electricity has various properties, the principal of which are:—

(*a*) **Heating.** When electricity "flows" along a wire, if the wire be thin and the current strong, the wire will be heated by the passage of the electricity.

(*b*) **Magnetic.** When electricity "flows" along a wire, it sets up invisible circular magnetic lines of force round the wire. If the current be strong enough, the wire will be able to pick up iron filings while the current is passing.

(*c*) **Chemical.** If electricity is passed through certain chemical solutions, it will split them up into their constituents. Thus, if electricity be passed through water, the water will be split up into the two gases, Hydrogen and Oxygen, of which it is composed.[1]

70. **Heating Effect of a current.** Whenever electricity flows through a conductor, that conductor always becomes heated to a certain extent, because there is no substance which will allow electricity to flow through it without offering some *resistance* to its passage, and it is in overcoming this resistance that the current develops heat.

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[1] A few drops of sulphuric acid must be added to the water, to make it conduct better.

If the wire be of a good conducting substance, such as copper, and if it be thick, and if the current be not very strong, the heat developed will be so little as to be hardly noticeable. On the other hand, if the wire be of a material which is not so good a conductor as copper, such as iron or german silver,[1] and if the wire be thin, the passage of a strong current will make it red hot. This is the principle of the *incandescent* or *glow lamps* so much used in electric lighting. The electricity is made to pass through a wire or filament of carbonised material enclosed in a glass globe, from which all the air has been extracted. The reason for pumping the air out of the globe, is, that if the carbon filament were heated in air, it would immediately oxidise, or burn away.

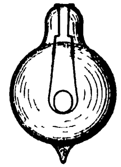

FIG. 37. GLOW LAMP.

71. **Magnetic Effect of a Current** (Fig. 38). If a sufficiently strong current be passed through a wire, and the wire dipped into iron filings, the filings will adhere to the wire as long as the current is "on," but will drop off directly the current is stopped. This proves that when electricity "flows" through a conductor, that conductor, or rather, the space around it, becomes magnetic, and remains so as long as any current is passing. We cannot have magne-

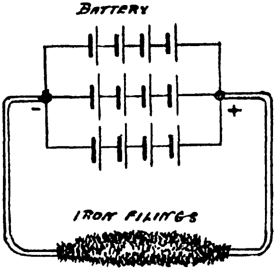

FIG. 38. MAGNETIC EFFECT OF A CURRENT.

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[1] German silver is an alloy made of copper, nickel, and zinc.

tism without lines of force (§ 17), therefore a current-carrying conductor must have lines of force round it. The battery, arranged as shown in the figure, should be composed of Bichromate or Bunsen cells.

72. **Magnetic Field round a Wire carrying a Current.** To show how the lines of force round a conductor arrange themselves, fix a thick copper wire upright through the centre of a piece of cardboard, as shown in the Fig. 39; pass a current through the wire from a strong battery (say three parallel rows of four bichromate cells in series), and sprinkle iron filings upon the cardboard. The filings will arrange themselves as shown in the figure, proving that

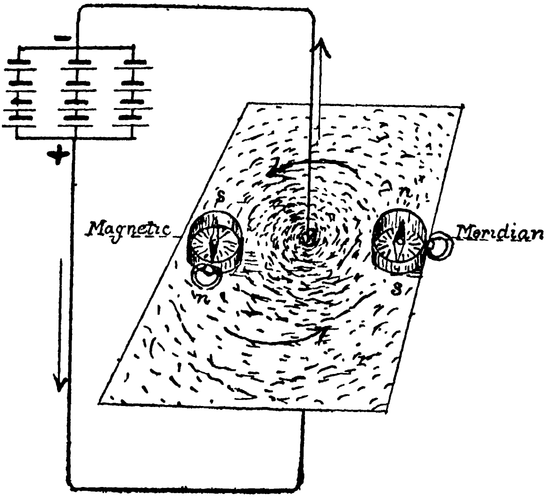

FIG. 39. MAGNETIC FIELD OF A CURRENT.

the magnetic field of the wire is made up of circular lines of force. Fig. 40 is an imaginary picture of a wire carrying a current, and encircled by the lines of force. Whenever a current, however weak, passes along a conductor, a magnetic field is set up round that conductor, but the lines of force cannot be detected by means of iron filings in the manner just described, unless the current be very strong. In the next paragraph we shall see that a much more delicate method of detecting their presence, (and therefore, also, the existence of a current), is by means of a magnetic needle (§ 13).

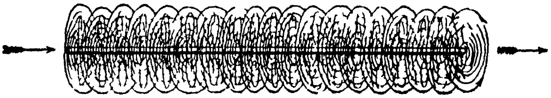

FIG. 40.

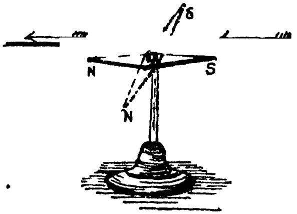

FIG. 41. DEFLECTION OF A MAGNETIC NEEDLE BY A CURRENT.

73. **A Current in a Wire deflects a Magnetic Needle.** From what was said in § 27, it should be evident that if we bring a freely suspended magnetic needle near to a wire along which electricity is passing, the needle will be influenced by the magnetic field of the current in the wire. Take a horizontal magnetic needle (§ 13), poise it on its pivot, and when it has come to rest, stretch a wire above or below it, and parallel with it. If the ends of

wire be now connected to the poles of a battery, directly the circuit is completed, the needle will move from its position of rest, and lay itself more or less at right angles to the wire, according to the strength of the current.

74. **Direction of Magnetic Field round a Wire carrying a Current.** Referring again to § 27, it will be clear that when a current deflects a neighbouring magnetic needle, the needle will try to lay itself along one of the lines of force, but as it cannot do that, the lines of force being circular, it does the best it can, as shown in Figs. 39 and 42, which give different positions of a needle round the vertical wire. In such positions the needle is said to set itself as a tangent to the circular line of force. In the right-hand figure above, the current is supposed to be flowing down through the paper, while in the left-hand figure it is supposed to be flowing up.

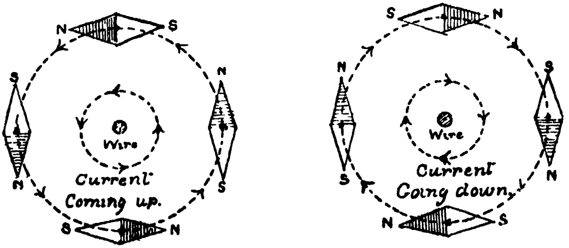

FIG. 42. DEFLECTION OF MAGNETIC NEEDLE BY A CURRENT.

The needle cannot set itself quite at right angles to the wire, because, it must be remembered, there are two forces acting on the needle: first, the magnetism of the earth, tending to bring it back to its first position; and secondly, the magnetism of the current, tending to turn it at right angles to the wire. The needle therefore takes up an intermediate position dependent on the relative strengths of the earth's and of the current's field. This is supposing that the wire is stretched parallel with the needle's position of rest, *i.e.* in the magnetic meridian. The + direction along the lines of force depends upon the direction of the current in the wire, and is indicated by the pointing of the N. poles of the needles shown in Figs. 39 and 42.

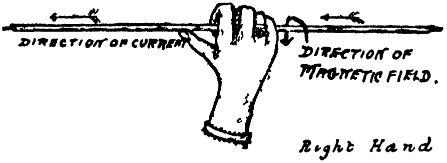

FIG. 43. FINDING DIRECTION OF MAGNETIC FIELD ROUND A CURRENT-CARRYING WIRE.

Looking at the end of the wire (Fig. 42), if the current is flowing towards you, the direction of the lines of force is anti-clockwise; if the current is flowing from you, their direction is clockwise.[1]

75. **Right-hand Rule for finding the + direction round the Magnetic Field of a Wire carrying a Current** (Fig. 43). *Place the right hand across the wire with the thumb point-*

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[1] *Clockwise*, the direction in which the hands of a clock move; *anti-clockwise*, the opposite direction to that in which the hands of a clock move.

ing in the direction of the current, then the fingers will denote the + direction along the wire's circular lines of force.[1]

76. Right-hand Rule for finding the direction of deflection of a Magnetic Needle by a Current in a Wire. (Jamieson.) *Place the right hand on the wire with the palm facing the needle, and the fingers pointing in the direction of the current: then the outstretched thumb will denote the side of the wire to which the N. pole of the needle will move. The wire must be between the needle and the hand.* (Fig. 44.)

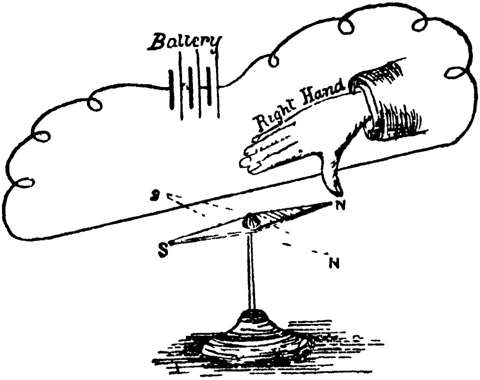

FIG. 44. FINDING DIRECTION OF DEFLECTION OF A MAGNETIC NEEDLE BY A CURRENT.

77. Right-hand Rule for finding the direction of the Current in a Wire. (Jamieson.) The rule in § 76 enables us to foretell the way in which the N. pole of a needle will turn when influenced by a current in a wire. The rule we shall now give is the converse of this, and is much more useful, as, having noted the deflection of a compass needle brought near the wire, we can tell therefrom the direction in which the current is flowing.

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[1] This rule was devised by Mr. Cullingford, one of the Author's students.

Rule. (1) *Move the wire (if possible) into the magnetic meridian.* (2) *Place a freely suspended compass needle above or below the wire, and observe the direction in which the N. pole of the needle points.* (3) *Place the right hand on the wire with the palm facing the needle, so that the outstretched thumb points in the direction that the needle is pointing, then the fingers will denote the direction in which the current is flowing. The wire must be between the needle and the hand.* (Fig. 45.)

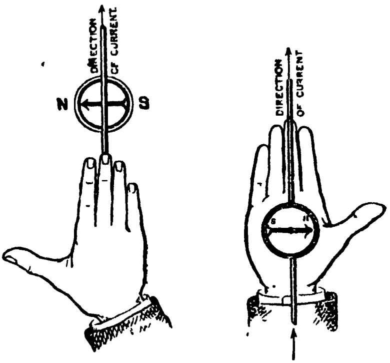

FIG. 45. FINDING DIRECTION OF CURRENT IN A WIRE.

78. **Œrsted's Stand.** The apparatus devised by Œrsted, and shown in Fig. 46, is extremely useful for illustrating the magnetic action of a current upon a magnetic needle. It consists of two stout copper or brass wires, W_1 and W_2, about six inches long, fixed one above the other (half an inch apart), into two wooden uprights. The ends of the wires are provided with terminals, T_1, T_2, T_3.

and T$_4$. The needle is pivoted midway between the two wires.

By means of this apparatus currents may be sent in either direction along the top or bottom wires; or at the same time in both wires, in the same or opposite directions; and their effects upon the needle studied.

79. **Experiments with the Œrsted Stand.** (*a*) Send the current through the top wire from T$_1$ to T$_2$; the N. pole of the needle will move away from the observer if he stands so that the apparatus faces him, as shown in Fig. 46.

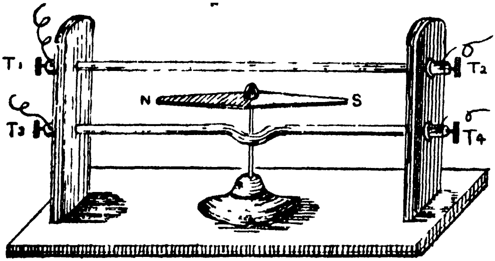

FIG. 46. ŒRSTED STAND.

(*b*) Reverse the direction of the current, *i.e.* make it flow from T$_2$ to T$_1$; the N. pole of the needle will move towards the observer.

(*c*) Send the current through the bottom wire from T$_3$ to T$_4$. The needle's N. pole will turn towards the student.

(*d*) Reverse the direction of the current, *i.e.* make it pass from T$_4$ to T$_3$, and the direction of deflection of the needle will be also reversed.

(*e*) Join T$_2$ and T$_3$ by a long wire, so placed as to have as little effect of itself upon the needle as possible, and send a current from T_1 to T_4; hardly any movement of the needle will be discernible if it is exactly half way between the two wires.

(*f*) Send the current from T_4 to T_1, again hardly any movement of the needle will take place.

(*g*) Join T_2 and T_4 by a wire, and send the current from T_1 to T_3, or from T_3 to T_1; the movement of the needle will be greater than in either of the cases *a*, *b*, *c*, or *d*.

The student should apply the right-hand rule in each case before passing the current, and notice that the movement of the needle agrees with the rule. From these experiments it will be noticed that a current flowing, say, from right to left above the needle, will move it in the same way as a current flowing from left to right below the needle, and *vice versa.* Again, if the current be made to flow at the same time in top and bottom wires, and in the same direction (Experiments *e* and *f*), the needle will hardly move; but if the current be sent from right to left in the top wire, and back again from left to right in the bottom wire, or *vice versa: i.e.*, if the current be made to take a complete turn round the needle, the movement of the needle will be much greater than if the current only flowed above or below it.

80. **Simple Œrsted Stand.** Fig. 47 shows a simple form of Œrsted stand, in which the wire makes one complete turn round the needle. The student should notice that the movement of the needle is reversed when the direction of the current is changed, and apply the right-hand

rule to prove that a current flowing in one direction in the top half of the wire, has the same effect on the needle as a current flowing in the opposite direction, in the bottom half of the wire.

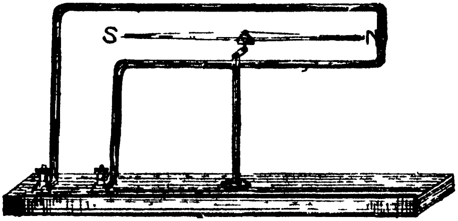

Fig. 47. Simple Œrsted Stand.

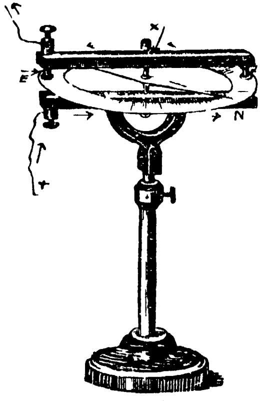

Fig. 48. Simple Horizontal Galvanoscope.

81. **Simple Horizontal Galvanoscope.** A *galvanoscope* or *detector* is an instrument for detecting the presence, direction, and relative strength of a current, *i.e.*, it first of all shows whether a current is passing; secondly, the direction of the current may be found by applying the right-hand rule; and thirdly, it will show whether one current is weaker or stronger than another. Fig. 48 represents a *simple horizontal galvanoscope* (so called because the needle swings horizontally), which is the same in principle as the simple Œrsted stand, but has in addition a divided card, so that it may be seen how far the needle swings

round, and consequently whether one current is weaker or stronger than another. The divisions on the card, however, do not in any way give a measure of the current. In using such a galvanoscope, or either of the Œrsted stands, it is important that the wires be parallel with the needle when the latter is at rest, *i.e.*, in the magnetic meridian.

82. Simple Vertical Galvanoscope. This instrument, shown in Fig. 49, has its needle pivoted so as to swing in a vertical plane. The bottom half of the needle should be slightly heavier than the top half, so that the needle shall always be upright when no current is passing. The bottom end of the needle should be its N. pole. The current is led once up the wire behind the needle, across the top, and down the front; and the principle of the instrument is therefore exactly similar to that of the horizontal galvanoscope: in fact, it may be looked upon

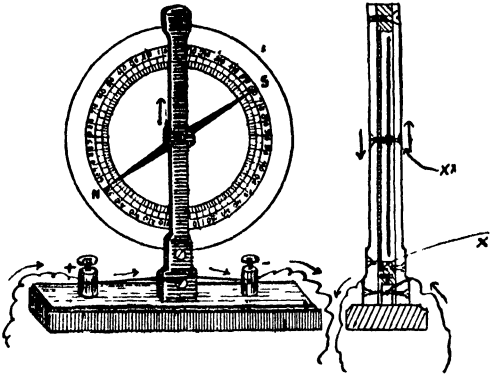

FIG. 49. SIMPLE VERTICAL GALVANOSCOPE.

spiral which points N., and repulsion will take place between the two; but if the S. pole of the magnet be used, attraction will take place. This proves that there is a magnetic N. pole at that end of the solenoid. In the same way it may be shown that the other end of the solenoid is a S. pole.

Thus we find that a wire spiral or solenoid, round which a current is passing, is practically a bar magnet as long as the current flows.

86. **Electro-Magnet.** Take a bar of soft iron, say six inches long, and wind round it two or three layers of pretty stout covered copper wire. Dip either end of the bar into iron filings or tacks, and of course the iron will be found to be unmagnetised. Now pass the current from three or four Bichromate cells through the wire, and again dip the end of the bar into the filings or tacks; the bar will be found to have become powerfully magnetic, and if its ends be tested by means of a small compass, one end will be found to be N., and the other S. Stop the current, and all the filings or tacks will drop off (if the iron has been well softened by heating). Such a magnet as this is called an electro-magnet, because its magnetism is due to the current of electricity in the coils of wire, and disappears as soon as the current is stopped (Fig. 6). If a bar of hardened steel were used in place of the soft iron, the magnetism imparted to it by the current in the coil would be permanent (§ 30).

87. **Horseshoe Electro-Magnet.** Fig. 53 represents three forms of horseshoe electro-magnet, in which, as was explained in connection with permanent horseshoe mag-

nets (§ 10), the two poles are brought near together, so as to be able to act on the same piece of iron. The piece of iron which an electro-magnet is used to attract is called

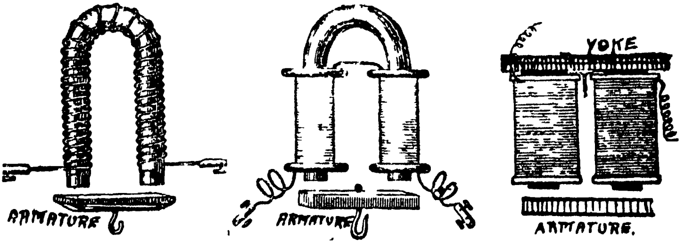

FIG. 53. THREE KINDS OF HORSESHOE ELECTRO-MAGNET.

its *armature.* The magnet shown to the right hand of Fig. 53 is made in three parts: two iron cores, which carry the coils, joined together at the back by a piece of iron called the *yoke.* The iron cores, yoke, and armature of every electro-magnet should be carefully annealed or softened (§ 8).

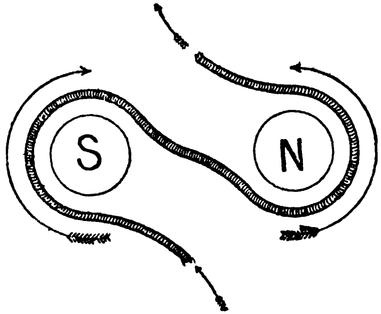

FIG. 54. POLARITY OF SOLENOIDS OR ELECTRO-MAGNETS.

88. **Polarity of Solenoids and Electro-Magnets.** An electro-magnet may be considered as a solenoid or solenoids, with a soft iron core or cores. Looking at the end of a solenoid, or of the coil of an electro-magnet, if the cur-

spiral which points N., and repulsion will take place between the two; but if the S. pole of the magnet be used, attraction will take place. This proves that there is a magnetic N. pole at that end of the solenoid. In the same way it may be shown that the other end of the solenoid is a S. pole.

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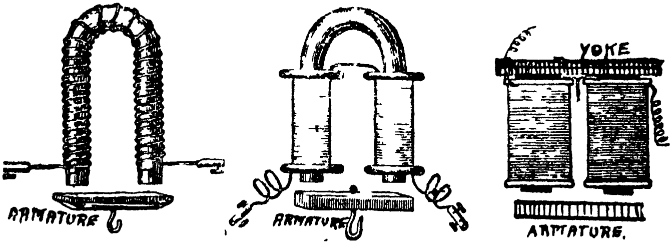

Fig. 53. Three Kinds of Horseshoe Electro-Magnet.

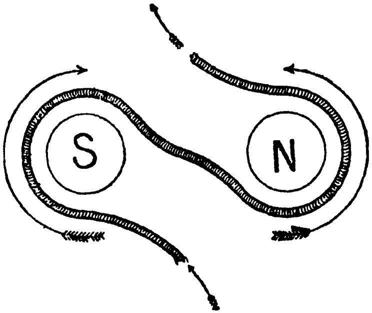

Fig. 54. Polarity of Solenoids or Electro-Magnets.

88. **Polarity of Solenoids and Electro-Magnets.** An electro-magnet may be considered as a solenoid or solenoids, with a soft iron core or cores. Looking at the end of a solenoid, or of the coil of an electro-magnet, if the cur-

rent is circulating right-handedly, *i.e.* in a clockwise direction, the end facing you will be a S. pole. If, on the contrary, the current is circulating left-handedly, the pole will be N. (Fig. 54.)

89. **Right-hand Rule for finding the Polarity of a Solenoid or of an Electro-Magnet.** (Jamieson.) *Place the right hand with the palm on the coil, and the fingers pointing round in the direction of the current, then the outstretched thumb will point towards the N. end of the solenoid or electro-magnet.* (Fig. 55.)

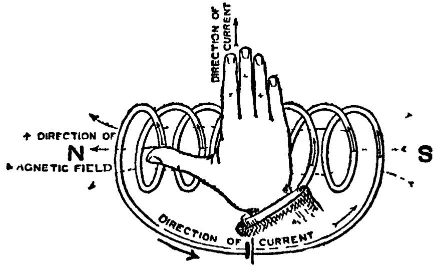

FIG. 55. FINDING POLARITY OF SOLENOID.

90. **Theory of Electro-Magnets.** In § 29, relating to the molecular theory of magnetism, we saw that every particle of iron or steel may be considered to be a little magnet, but in the unmagnetised state of the bar of iron or steel, these magnetised molecules complete their magnetic circuits amongst themselves, and there is consequently no free magnetism. The effect of passing lines of force through the bar is to set all the little molecules in line, and cause the bar to exhibit free magnetism. The mole-

cules of hardened steel when once set in line, remain so, hence steel may be permanently magnetised ; but with a soft iron bar, directly the lines of force are removed, the molecules jumble themselves up again, and the bar loses its magnetism. This is why an electro-magnet only exhibits magnetism while the current is passing. If a current be passed through a solenoid, it acts as a magnet; but if an iron core is inserted, the magnetic effect is much increased. Why is this? In the first case the magnetism is due to the lines of force of the current alone ; in the second case these lines of force, passing through the soft iron core, polarise it and bring into evidence its own latent magnetism: thus we have the lines of force due to the polarised bar, added to the lines due to the current, hence the increased effect.

91. **Use of Electro-Magnets.** When the student comes to study the practical applications of electricity, he will find that the electro-magnet is by far the most useful electrical device, as nearly every electrical instrument or machine depends for its action upon some kind or form of electro-magnet.

92. **Difference between Galvanoscopes and Galvanometers.** A **galvanoscope** is, as was explained in § 81, an instrument which will detect a current, its direction, and show whether it is weaker or stronger than another current. A **galvanometer** not only does this, but shows how much weaker or stronger one current is than another.

93. **Astatic Galvanometer.** In § 43 we explained the construction of astatic needles : an *astatic galvanometer* is one in which an astatic needle or needles are used. Fig.

56 represents the principle of the instrument, which is more completely shown in Fig. 57. The coil is generally wound in two halves, to enable the needle to be inserted. The bottom needle swings within the coil, the top one between the top of the coil and the dial. The dial is marked out in degrees or divisions. Fixed to the same axis, and parallel with the needles, is a light aluminium pointer or index (Fig. 56) which indicates on the scale how many degrees the needles have been deflected from zero. The needles are suspended by means of a delicate fibre of unspun silk. With an instrument such as is shown in Fig. 57, so long as the deflections of the needle do not exceed about 15°,[1] they may be taken as being directly proportional to the currents producing them.

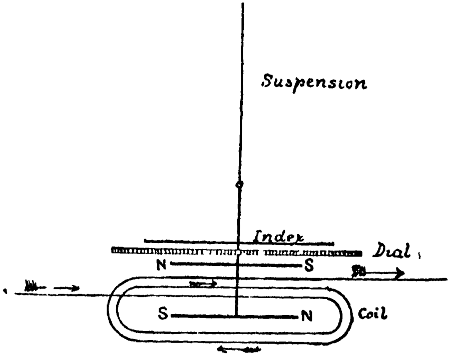

FIG. 56. PRINCIPLE OF THE ASTATIC GALVANOMETER.

As the needles are unaffected by the Earth's magnetism, it is necessary to have some controlling force to bring the needles back to zero after they have been deflected. This is accomplished by placing a small bar magnet beneath, or at the side of the base of the instrument. As the bottom needle is nearer the magnet than

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[1] 15° means 15 degrees.

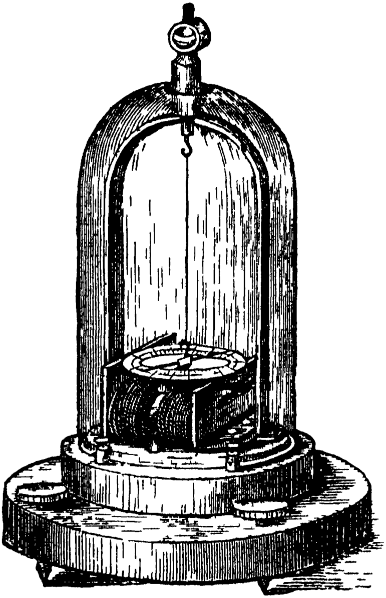

FIG. 57. ASTATIC GALVANOMETER

the top one, they as a whole are subject to the directive effect of the magnet, and the latter may be moved about until such a position is attained, that the pointer always comes back to zero after deflection. A magnet when used for this purpose is called a *controlling magnet.*

94. Chemical Effect of the Current. Electrolysis. The passage of electricity through certain chemical solutions splits them up into their constituents. This action of electricity is called *electrolysis* (electric analysis), and the solution which is split up is called the *electrolyte.* The current is led into and out from the solution by conducting plates of carbon, platinum, lead, or other metal, according to the nature of the solution which is to be *electrolysed.* The plate by which the current enters the electrolyte is called the *anode,* and the plate by which it leaves is called the *kathode.* The constituents into which the *electrolyte* is split up are called *ions:* they are liberated from the solution at the surface of the anode and kathode. The ion which appears at the anode is called the *anion,* and that which appears at the kathode, the *kathion.* The amount of chemical action effected by the passage of the current is exactly proportional to the strength of current, and the length of time it has been passing ; and is thus a measure of the quantity of electricity which has passed through the electrolyte. An *electrolytic cell* so arranged as to measure the amount of electrolysis, and therefore the quantity of electricity which has passed through, is called a *voltameter.*

95. Electrolysis of Water. Hoffmann's Voltameter. The electrolysis of water is very well shown by means of the apparatus depicted in Fig. 58, devised by Hoffmann, and called a voltameter, because the amount of electrolysis, *i.e.* the amount of gas given off by the passage of the current, may be measured by means of the scale marks on the glass tubes. The instrument consists of a U tube fitted with a stop-cock, SC, at each extremity. A longer tube, with a funnel, F, at the top, is connected with the U tube at its middle. At the bottom of each leg of the U tube is a platinum plate, Pt, connection between which and the outside, is made by means of platinum wires passing through and sealed in the side of the tube. Platinum is used because it is not acted upon by acidulated water, the water having to be so because pure water would be a very bad conductor (§§ 51, 69). To charge the apparatus, shut the stop-cocks, SC, SC, and pour acidulated water into the bulb until the tubes and bulb are full, then turn each stop-cock gently to let out the compressed air at the top of the tubes. Now connect a battery of three or four cells to the terminals of the instrument, and gas will be given off at both the anode and the kathode. Water is composed of two gases, hydrogen (H.), and oxygen (O.), in the proportions of H_2O_1, *i.e.*, 2 vols. of hydrogen united with 1 vol. of oxygen. Hydrogen is the kathion, and will consequently collect in the tube containing the kathode, *i.e.*, the platinum plate in connection with the — pole of the battery; oxygen being the anion, will be given off at the anode. After the electrolysis has been going on for a few minutes, it will be noticed that about twice as much H. as O. has been given off. The gases may be

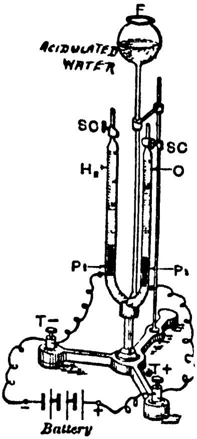

FIG. 58. HOFFMANN'S VOLTAMETER.

tested as follows: the H. will burn with a pale blue flame if the stop-cock be opened and a match applied. The O. does not burn, but will reignite a glowing match if one be held over the stop-cock, for O. is a good supporter of combustion.

96. **Electrolysis of Copper Sulphate.**— Take a gallipot filled with a saturated solution of sulphate of copper, such as is used in the Daniell cell. Cut two strips of sheet lead about 4 inches long and 1½ inches wide, and clean the surface well with emery paper. Fix a bindscrew to one end of each piece, and bend them into a ſ shape, so that they may be conveniently hung over the edge of the gallipot, facing each other, but not touching.

Experiment. Use a battery of two cells, connect the poles of the battery with the strips of lead, and pass a current through the solution for about ten minutes. Now take out the plates and examine them: the plate in connection with the — pole of the battery, *i.e.*, the kathode, will be found to have received a bright red deposit of pure copper; while the other plate will have become dirty and discoloured, due to oxidation. The passage of the electricity splits up the sulphate of copper ($SO_4Cu.$) into SO_4 and Cu.; the Cu. is deposited on the kathode, and the SO_4 is liberated at the anode, which in this case it attacks and oxidises, forming as well a small quantity of lead sulphate ($Pb.SO_4$). If arrangements be made for accurately weighing the amount of copper deposited from the solution, the instrument becomes a voltameter.

97. **Electroplating and Electrotyping.** The processes of electroplating and electrotyping depend upon the libera-

tion of metals from solutions of their compounds, by electrolysis. In *electroplating*, the object, such as a spoon, fork, cup, dish, etc., generally of cheap metal, is coated with gold, silver, cobalt, or nickel.

The article to be plated is hung in a *bath* containing a solution of the metal to be plated. The article, of course, forms the kathode, being connected with the — pole of the battery. The anode is generally a plate of the same metal as is being plated, and dissolves into the solution as fast as metal is deposited upon the kathode, thus keeping up its strength.

In *electrotyping*, a copy of an object is obtained without injuring or altering the object itself. This is effected by properly preparing the surface of the object, and then depositing a coating of metal (generally copper), which may afterwards be removed. Or casts of the object are taken in plaster of paris, gutta-percha, sulphur, etc., the surface of the cast being then rendered conducting by brushing it over with gold size, or finely powdered plumbago, and the metal deposited upon that.

A copy of an object obtained in this manner is called an *electrotype*.

97*a*. **Induction of Currents. Electromagnetic Induction.** If a wire forming part of a closed circuit be moved through a magnetic field, at right angles to the lines of force, a momentary *induced current* will flow through the wire. If the wire be moved back again, another momentary current will be induced in it, in the opposite direction to the first current. Thus, in Fig. 59, *a b* is a wire connected up with a very sensitive galvanoscope or galvanometer, G. An astatic galvanometer, wound with a great length of fine wire, will do very well. N is the pole of a strong magnet. G must be as far away from N as possible, well out of reach of its direct influence. *Experiment.* Hold the wire *a b* above the magnet as shown. Pass it down quickly in front of the magnet's pole, and the galvanoscope will immediately indicate the passage of a momentary current. Bring the wire quickly up again to its first position, and another momentary current will flow through the galvanoscope, in the opposite direction to the first current. If the motion of the

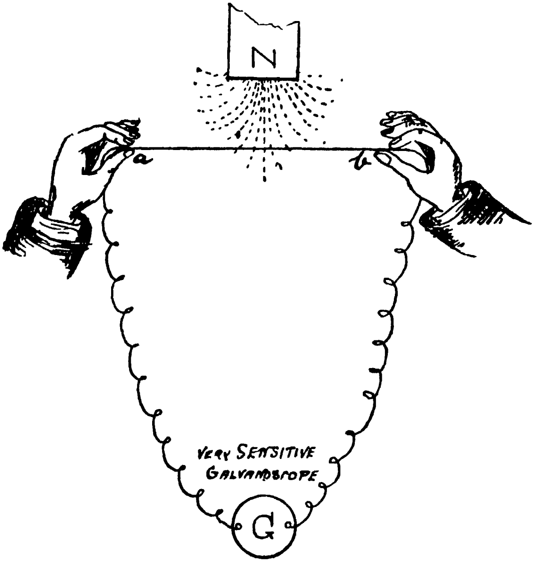

FIG. 59. INDUCTION OF CURRENTS.

wire *a b* up and down in front of the pole of the magnet were kept up, momentary currents, first one way and then the other, (or what electricians would call an *alternate current*), would be continuously induced in the wire. The stronger the magnetic field, *i.e.* the greater the number of lines of force, and the quicker the motion, the greater will be the strength of the induced currents. An elementary way of accounting for this induction of currents is as follows. We know (§ 71) that whenever a current flows along a wire a magnetic field is set up round the wire. It might therefore be expected, and we have seen that such is actually the case, that if a magnetic field is brought near a wire, currents will be induced in the latter.

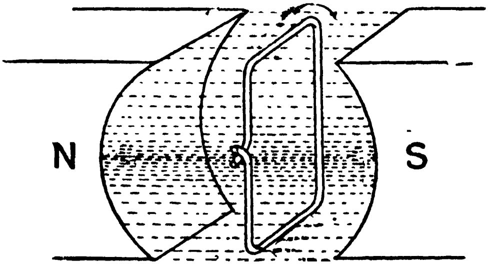

FIG. 60. ARMATURE COIL IN MAGNETIC FIELD.

97*b*. **Simple Dynamo.** The dynamo (§ 67*a*) depends for its action upon electromagnetic induction, but in a simple dynamo the wire is wound into a coil, and revolved in the magnetic field between the poles of a horseshoe magnet, generally an electro-magnet.

Fig. 60 represents a single coil of wire in the magnetic field between the poles N and S of a magnet.

If the coil be rapidly spun round, currents will be induced in it, first in one direction and then in the other, as long as the motion is kept up, provided the ends of the coil are joined by a wire, or provided the coil forms part of a complete circuit. When a current flows round a coil, such as a solenoid, lines of force are set up, which pass right through the coil; and the direction of the lines depends on the direction of the current in the coil (§ 84). Therefore it follows that if we take a coil and poke lines of force through it, a current will be set up in the coil: if the lines of force are taken out and poked through the other way, another current is set up, in the opposite direction to the first current. This is exactly what happens with the coil in the figure: as it turns round, the lines of force pass through it first in one direction and then in the other, and consequently, alternate currents are set up.

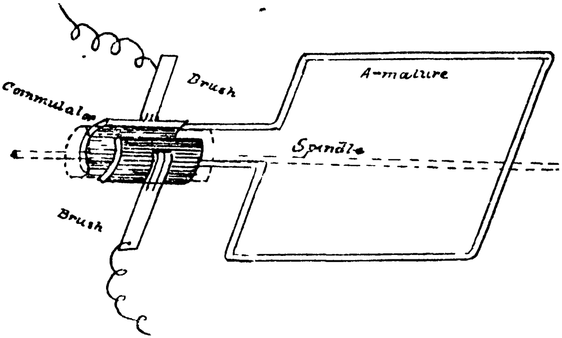

FIG. 61. ARMATURE, COMMUTATOR, AND BRUSHES.

Fig. 61 shows how the currents in the coil or *armature* are made continuous in direction before they go into the outer circuit. The ends of the coil, which may have a number of turns, are connected each to a piece of split tube, mounted on an insulating boss fitted on the spindle. These constitute the *commutator*. As the coil goes round, the pieces of split tube (*commutator segments*) revolve between two *brushes* made of copper strip or wire. These brushes are in connection with the outside circuit. As the currents in the armature change in direction, the connection of the armature with the external circuit is reversed, by means of the commutator and brushes, consequently the induced currents flow through the external circuit always in the same direction.

Most small dynamos consist of three parts: (*a*) The *field magnet*, which furnishes the lines of force; (*b*) the *armature*, generally consisting of several coils of wire mounted together; and (*c*) the *commutator* and *brushes*.

97*c*. Dynamo. Fig. 62 represents a form of dynamo. The field magnet has only one coil, which is placed in the centre of the C-shaped piece of iron. The armature is of a different kind to the one described in the preceding paragraph. It is called a *ring armature*, because its coils are wound around

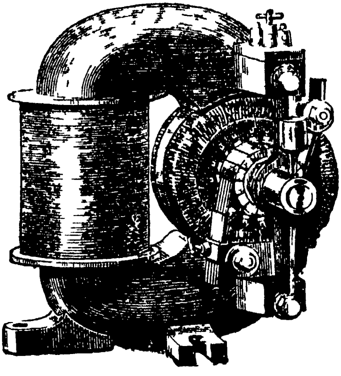

FIG. 62. DYNAMO

a ring made of soft iron plates or wire. The armature is mounted on a wooden hub, which in turn is fixed to the spindle of the machine. This spindle also carries the commutator. There are twenty-one coils of wire on the armature, and a corresponding number of commutator segments. The current, as it is collected from the commutator by the brushes, is led partly round the field magnet and partly through the external circuit. Thus, it will be seen, the machine excites its own field magnet. The spindle which carries the commutator and armature has at its further end a pulley, which enables the dynamo to be driven by an engine and belt.

97*d*. **Motor.** If a dynamo, instead of being driven by an engine, and used to give a current, has a current from a separate source (as from another dynamo, or from a battery) passed through it, its armature will revolve, and the dynamo becomes a kind of electric engine, capable of driving machinery. A dynamo when used in this manner, is called an *electro-motor*, or simply a *motor*.

END OF PART II.

QUESTIONS.

PART II.—ELECTROKINETICS, OR ELECTRICITY IN MOTION.

In answering these questions, give sketches wherever possible.

1. Say what you know about the theory of electricity.

2. What do you mean when you say that a body is in a state of negative electrification?

3. What is the meaning of the term *potential?*

4. Compare the meaning of the term *potential* in electricity, with that of the terms *height* and *depth* in ordinary usage.

5. Distinguish between a conductor and an insulator.

6. Arrange the following substances in their order of conductivity: glass, oil, brass, cotton, coke, india-rubber, wood, sulphur, water.

7. What occurs if pieces of different metals are placed in contact?

8. If two bodies are at different potentials, what is the result of connecting them together by means of a conductor?

9. What is a cell?

10. Explain fully the construction and action of the simple cell.

11. *Define:* exciting fluid, polarisation, — element of a cell, — pole of a cell, local action.

12. Give a full explanation of the cause of local action.

13. Say what you know about amalgamation, depolarising fluid, single and two-fluid cells.

14. Sketch and describe by an index of parts the Daniell and Fuller cells.

15. Rule six columns, headed respectively, *name of cell*, + *element*, − *element*, *exciting fluid*, *depolarising fluid or depolariser*, *E.M.F.*, and fill up particulars of all the cells you know.

16. What is the difference between cells arranged *in series*, and cells arranged *in parallel?*

17. *Sketch:* four cells in series; three cells in simple parallel; ten cells arranged in two parallel rows of five in series.

18. *Define:* E.M.F., circuit, current, porous pot, resistance.

19. What are the divisions of a circuit?

20. Enumerate the chief properties of an electric current.

21. If I take a yard of german silver wire, and a yard of copper wire of exactly the same size, and send the same strength of current through each, why is it that the german silver wire becomes so much hotter than the copper wire?

22. What do you know about incandescent lamps?

23. A wire carrying a strong current when dipped into iron filings, attracts them. Why is this?

24. Give a sketch of the magnetic field due to a current in a straight conductor.

25. If a wire dipped into iron filings fails to pick any

up, is it a proof that there is no electricity flowing through the wire ?

26. In how many ways could you detect the passage of a strong current through a wire ?

27. Supposing a wire stretched from the floor to pass through the ceiling of a room: if you looked up at the ceiling, what would be the + direction around the magnetic field, if a current were flowing from floor to ceiling ?

28. Give a sketch illustrating the forces which act upon a magnetic needle due (*a*) to the magnetism of the Earth ; and (*b*) to a current passing by the needle from S. to N.

29. Give a sketch illustrating how, by means of your right hand, you can ascertain the + direction along the field, when you know which way a current is flowing in a wire.

30. A wire running across a room, and out through the two walls, carries a current. Explain with sketches how, with the help of a pocket compass, you could ascertain the direction of the current in the wire.

31. If a wire were stretched under a magnetic needle, and a current were sent along the wire, how could you tell beforehand to which side the S. pole of the needle would turn ?

32. Explain in as few words as possible the use of Œrsted stands, and give a sketch of each kind.

33. What conclusions do you arrive at after you have performed all the experiments, *a* to *g*, mentioned in § 79 ?

34. *Define:* galvanoscope, galvanometer, detector, solenoid.

35. If a simple Œrsted stand be so placed that the wire lies E. and W., would it in any case be possible to get a current to move the needle?

36. Give a side view of a simple vertical galvanoscope, showing clearly the course of the current round the needle.

37. Does it strike you that there is any difficulty about the fixing of the needles of the simple galvanoscopes shown in Figs. 48 and 49?

38. Is it absolutely necessary that the wire used in the construction of the horizontal galvanoscope, shown in Fig. 50, should be insulated? If so, why? If not, why not?

39. Draw a bar magnet, and a current-carrying solenoid, side by side, with the magnetic field due to each.

40. Sketch and describe fully, by an index of parts and otherwise, the construction of the apparatus shown in Fig. 52.

41. What is the difference between an electro-magnet and a permanent magnet?

42. Given a bar of soft steel with one end marked, a solenoid, and a battery: how would you permanently magnetise the steel bar so that the marked end should be a N. pole?

43. Given bars of annealed iron, unsoftened iron, hardened steel, and soft steel, a solenoid, and a battery: if each bar in turn were placed in the solenoid for five minutes or so, while the current was "on:" what should

you expect would be the result of afterwards dipping each bar into iron filings? Give full reasons for your answer.

44. If a bar of hardened steel were placed in a current-carrying solenoid, and allowed to remain for five minutes; and were then taken out and placed in the other way for two minutes: what should you expect to be the magnetic condition of the bar, and why?

45. *Define:* electro-magnet, armature, electrolysis, electrolyte.

45*a*. How could you ascertain the polarity of a solenoid or of an electro-magnet, knowing the direction of the current in the wire?

46. Explain fully why, without altering the strength of current in a coil of wire, the insertion of a bar of soft iron should so greatly increase the magnetic effect.

47. Explain the construction and action of the astatic galvanometer.

48. If in such an instrument a pair of needles were used, having their like poles adjacent, would a current in the coils deflect the pair? If so, to what extent? If not, why not?

49. What is the chemical effect of the current?

50. *Define:* electrolysis, electrolyte, electrolytic cell, anion, kathode.

51. Two plates, one of copper, the other of wood, are placed opposite each other in a solution of sulphate of copper, and connected with the poles of a battery. Say what will occur, and why?

52. What is meant when it is said that a chemical solution is electrolysed?

53. *Define:* ion, voltameter, bath, electrotype.

54. Sketch and describe Hoffmann's voltameter, and say why it is so called.

55. Explain what takes place when electricity is passed through (*a*) acidulated water; (*b*) pure water.

56. If you had two tubes filled respectively with H. and O., how you would ascertain which was which?

57. Sketch and describe the apparatus used in the electrolysis of copper sulphate.

58. Explain the action which takes place when electricity is passed through copper sulphate.

59. What is the difference between electroplating and electrotyping?

60. How would you gold-plate a silver vase?

61. How would you obtain an electrotype copy of a medal?

62. Describe a simple experiment illustrating the induction of currents in a straight wire.

63. Upon what does the induction of currents in a straight wire depend?

64. Upon what does the induction of currents in a coil depend?

65. *Define:* electromagnetic induction, induced current, alternate current.

66. Describe fully the principle of the simple dynamo.

67. *Define in your own words:* field magnet, armature, and commutator.

68. How is the field magnet of a dynamo excited or magnetised?

69. Explain the difference between a ring armature and a simple armature.

70. Distinguish between a dynamo and a motor.

71. If an engine were some miles away from certain machinery, how could you carry the power of the engine to the machines by means of two dynamos, and a requisite length of wire? Give a sketch.

In answering these questions, give sketches wherever possible.

PART III.

ELECTROSTATICS, OR ELECTRICITY AT REST.

N.B.—Before commencing this Part, the student should read again §§ 44 *to* 51 (*inclusive*).

98. **Derivation of the word ELECTRICITY.** The first recorded electrical experiment was that of a Greek philosopher, Thales; who, 600 B.C., found that amber when rubbed with woollen materials, acquired the electrical property of attracting light bodies. The Greek for amber is ἤλεκτρον (elektron), and from this the word *electricity* is derived.

99. **Electrification by Friction.** If a stick of sealing-wax be rubbed briskly upon the coat sleeve, and then held over some small pieces of tissue paper, the pieces of paper will jump up to the sealing-wax when the latter approaches them. The rubbing of the sealing-wax has caused it to assume an electrified condition, in consequence of which it is enabled to attract light bodies to itself.

Electrification is developed when any two unlike surfaces are rubbed together, but the degree of electrification produced depends upon the substances used (§ 122).

100. **Electrification of Glass.** Take a clean, dry, warm glass rod or tube about two feet long, hold it by one end only, and rub the other end briskly with a piece of

warmed silk. Hold the rod over small pieces of paper, sawdust, feathers, etc , spread out on a tea-tray. The pieces of paper, etc., will dance up and down between the electrified glass rod and the tray. This new property of attraction, acquired by the glass rod, is entirely due to its being rubbed with the silk. If the surface of the silk rubber be smeared with "electric amalgam," as it is called,[1] the electrification developed on the glass rod will be all the greater. The rod should be held at its extremity, not as shown in the figure, or the moisture of the hand will carry the electricity away.

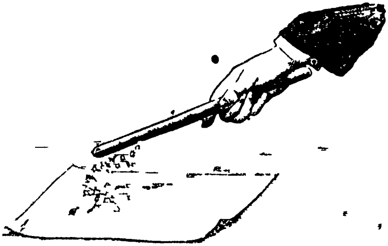

FIG. 63. ATTRACTION OF LIGHT BODIES BY AN EXCITED GLASS ROD.

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[1] **"Electric amalgam"** is made as follows: Melt 1 oz. of tin in a plumber's ladle, add gradually 1 oz. of zinc, and afterwards 2 oz. of mercury. The contents of the ladle should be continually stirred with a piece of iron wire. When cool, put up in a glass-stoppered bottle. When any of the amalgam is required for use, put a sufficient quantity on a board, and mix with dried lard by means of a spatula or flexible knife. Then apply to the surface of the silk rubber.

101. Electrification of Sealing-Wax and Ebonite. If the above experiment be repeated with rods of dry warm sealing-wax and ebonite, rubbed with flannel or fur, the same results will be obtained.

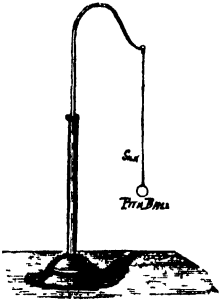

FIG. 64. SUSPENDED PITH BALL.

102. Other Experiments on the Attraction of Light Bodies. Instead of the pieces of paper, etc., the above experiments on electrical attraction may be better shown by using a blown egg-shell laid on the table, a suspended pith ball (Fig. 64), or a suspended wooden lath (Fig. 65).

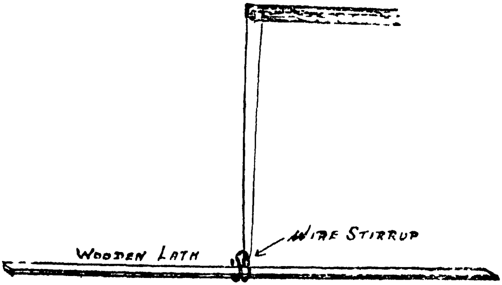

FIG. 65. SUSPENDED WOODEN LATH.

102*a*. **The Attraction between an Electrified and a Non-Electrified Body is Mutual.** Suspend in the wire stirrup (Fig. 65)[1] an excited glass or ebonite rod; present an unelectrified body, the clenched hand, for instance, and the excited rod will be attracted. This proves that an electrified body not only attracts, but is attracted by a non-electrified body.

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[1] If the stirrup be hung on a single thread, the weight of the suspended rod will cause the thread to untwist, and the rod to spin round. The method of suspension shown above is called *bifilar suspension*.

103. **Electrification of Brown Paper.** Take a well-warmed drawing board, a sheet of hot brown paper, and a well-dried clothes brush. Lay the paper on the board, and rub it briskly to and fro with the brush. If the paper be then presented with its rubbed side towards the light bodies on the tray (§ 100), or the suspended pith ball, or the suspended wooden lath: electrical attraction will take place, proving that the surface of the paper has been electrified. If the brown paper be presented to the wall of the room, it will cling to it so long as it retains its charge.

104. **Apparatus must be perfectly dry and warm, and free from dust.** The electrification developed by friction is at a very much greater potential or pressure than the electrification due to a battery, and for this reason, the slightest moisture on the surface of otherwise insulating bodies, renders them comparatively good conductors: consequently, these experiments will not succeed unless every care be taken to drive away moisture, by having the apparatus perfectly dry and warm (§ 50). Everything should as well be quite clean and free from dust, for dirt and dust are almost as good conductors of high pressure electricity as moisture.

105. **Electrical Repulsion.** Take a clean, dry, warm glass rod, rub one end of it with the amalgamated silk, and suspend it, without touching the rubbed end, in a

wire stirrup hung at the end of a silk thread (Fig. 65). Now rub a similar glass rod, and bring its rubbed end near to the rubbed end of the suspended glass rod. Repulsion will take place between the two, the suspended glass rod turning away from the one which you hold in your hand. In the same manner it may be shown that similarly rubbed rods of ebonite, sealing-wax, resin, or sulphur will repel each other when rubbed with a piece of dry flannel or fur.

106. **An Insulated Unelectrified Body is first Attracted and then Repelled by an Electrified Body.** Suspend a pith ball, empty egg-shell, or other light body by means of six or eight inches of dry silk thread. Present an excited glass tube or stick of ebonite. The pith ball will first be attracted, touch the excited rod, and then repelled. The electrified body gives some of its charge to the ball when the latter touches it, and then repulsion takes place, because, as we shall see further on, *bodies charged alike repel one another*.

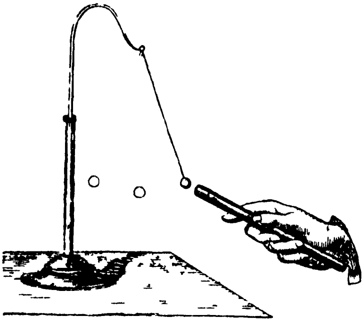

FIG. 66. ATTRACTION AND REPULSION OF A PITH-BALL.[1]

If the silk thread be damp, or if cotton be used, the suspended body will be uninsulated, and when attracted to the excited rod will stick to it, the charge on the rod leaking away through the conducting thread to earth (§ 118).

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[1] The excited rod should be held by its extremity, not as shown in the figure.

So far we have learnt:—

(1) That an electrified body attracts and is attracted by non-electrified bodies.

(2) That the same substances when rubbed with the same rubbers repel each other.

(3) That bodies electrified alike repel one another.

107. **Attraction between Electrified Bodies.** In the preceding paragraph we saw that a glass rod rubbed with amalgamated silk, repelled another glass rod which had likewise been rubbed with amalgamated silk; and also that an ebonite rod rubbed with flannel or fur, repelled another ebonite rod similarly excited.

Experiment (*a*). Suspend in the stirrup (Fig. 65) an unelectrified rod of ebonite, sealing-wax, sulphur, or shellac; excite the glass rod, bring it near, and attraction will take place, as we should expect, between the electrified and the unelectrified body.

Experiment (*b*). Rub the ebonite or sealing-wax rod, and suspend it in the stirrup; excite the glass rod, bring it near to the rubbed end of the ebonite rod, and *attraction* will take place between them; but in this case, the attraction will be much stronger than when the ebonite rod was unelectrified.

108. **+ (Positive) and — (Negative) Electrification.** In §§ 46 and 47 we spoke of there being two kinds or states of electrification, and it has just been shown experimentally that such is the case; for we found that the

electrification of glass when rubbed with silk, is different from the electrification of ebonite, sealing-wax, sulphur, or resin, rubbed with flannel or fur. As a matter of fact, the glass is said to be in a state of + electrification when rubbed with silk, and the ebonite, etc., in a state of − electrification when rubbed with flannel or fur.

109. **Charge.** An electrified body is said to have had a charge of electricity imparted to it. A body in a state of + electrification is said to be +ly[1] charged, or to have a charge of + electricity. Similarly, a body in a state of − electrification is said to be −ly charged, or to have a charge of − electricity.

Wherever possible, the student should use the terms + and − electrification, in preference to the terms + and − electricity, or he will be apt to fall into the erroneous idea that there are two kinds of electricity. It is convenient to think of but one kind of electricity—an indefinable something—which may exist in a body in a state of surplus (+ electrification), or deficit (− electrification) (§ 46).

110. **First Law of Electrostatics.** It has been shown that two +ly charged bodies repel each other, and likewise two −ly charged bodies; but that a +ly and a −ly charged body attract each other. From these facts is derived the first law of electrostatics: *Like charges repel, unlike charges attract.*

111. **Attraction does not always prove that two Bodies have unlike Charges.** A body +ly charged will attract a suspended −ly charged body, and a −ly charged body

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[1] +ly = positively, −ly = negatively. See footnote, p. 33.

will attract a suspended +ly charged body. If attraction takes place between a body held in the hand and a suspended body, it is perfectly certain that one or the other are electrified, but it is not certain that *both* are electrified. The body held in the hand might be charged and the suspended body have no charge at all; or the suspended body might be charged, and the body held in the hand uncharged; and yet attraction would take place in either case.

112. **The Gold-Leaf Electroscope.** Just as a galvanoscope enables a current of electricity and its direction to be detected, so an *electroscope* is an instrument for detecting the presence of an electrical charge on a body, and if the charge is + or −. An *electrometer* is a more delicate apparatus, which, in addition, measures the actual charge or amount of electricity on a body. The gold-leaf electroscope is so called, because its essential part is a pair of gold leaves hung side by side. These repel each other and open out when a charge is imparted to them, because any two bodies similarly charged repel each other. Its construction will be clear from Fig. 67, which represents the simplest form of the instrument.

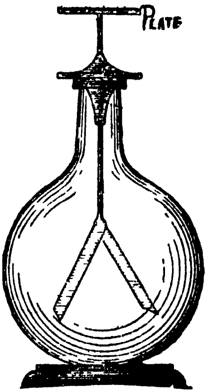

FIG. 67. GOLD-LEAF ELECTROSCOPE.

A glass flask or jar is thoroughly cleansed and dried, and furnished with a well-fitting stopper of cork, india-rubber, or wood. Through the stopper passes a brass rod carrying at the top a metal disc or plate, and at its lower extremity a pair of gold leaves.

113. **Uses of the Gold-Leaf Electroscope.** The gold-leaf electroscope may be used to:—

(1) Detect if a body is charged or not.
(2) Show if a charge is + or −.
(3) Show if a substance is a conductor or an insulator.

114. **Proof Planes.** A proof plane is a kind of electrical spoon, whereby part of the charge on a body may be taken from it and removed, say, to an electroscope, for examination. It consists of a conductor fixed at the end of an insulating handle of ebonite or varnished glass, and is used by touching the charged body with the conducting part of the proof plane, which, while in contact, becomes virtually part of the charged body itself, and so acquires a portion of its charge, which may then be removed. Fig. 68 shows various forms. In using a proof plane care must be taken to see that the insulating handle is perfectly clean and dry, and to take hold of it only by its extremity.

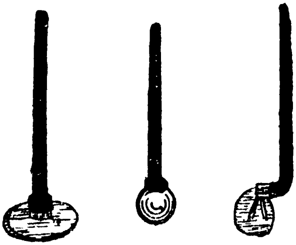

Fig. 68. Proof Planes.

115. **To find by means of the Gold-Leaf Electroscope if a Body be charged or no.** Bring the body up to the plate of the electroscope; if it be charged, the leaves of the electroscope will diverge or open out, and will diverge more and more as the body gets nearer. Or the body may be tested by touching it for an instant with a proof plane. If it be

charged, it will impart some of its charge to the proof plane, as would be shown by the divergence of the leaves of the electroscope when the proof plane was brought up to it.

116. **To charge an Electroscope +ly or −ly.** An electroscope may be charged positively or negatively, by bringing into contact with its *plate*, a +ly or −ly charged body, when some of the charge of the body will be imparted to the electroscope. Or part of the charge on the body may be given to the electroscope by means of a proof plane. These methods are bad ones however, for the sudden charge received by the electroscope may cause the gold leaves to diverge so violently, as to fly off from their support.

The proper way to charge an electroscope is by *electrostatic induction* or *influence*, the manner of which will be now described ; but an explanation must be deferred until the student has learnt something of *influence*. (§ 123.)

To charge an electroscope +ly, by influence. Bring over the plate of the electroscope a −ly charged body, such as an ebonite rod rubbed with flannel : the leaves will diverge more and more as the charged rod approaches. When the leaves are opened out to a sufficient extent, hold the ebonite rod perfectly steady over the electroscope, and touch the plate with the forefinger of the other hand. The leaves will converge or come together. Remove your finger from the plate, and then take away the charged rod, and the leaves will diverge or open out with a + charge.

To charge an electroscope −ly, by influence. Proceed exactly as explained above, but use a +ly charged body, such as a silk-rubbed glass rod, instead of a −ly charged one.

The student will notice that in charging an electroscope by influence, if a + charge is wanted in the instrument, a −ly charged body is used; if a − charge is required, a +ly charged body is used (§ 126).

117. **To ascertain by means of Electroscopes if the Charge on a Body is + or −.** Have two electroscopes on the table before you, one +ly and the other −ly charged.

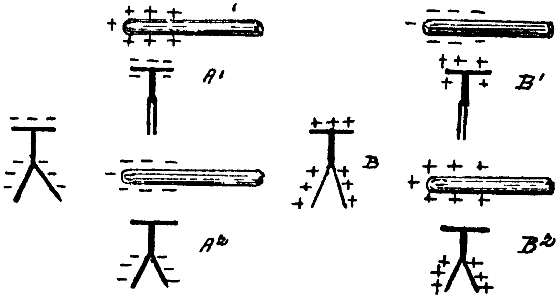

FIG. 69. TESTING + AND − CHARGES.

Bring the body whose charge is to be examined near to the plate of, say, the +ly charged electroscope. The leaves will either converge or diverge. Similarly, if the charged body be brought near the plate of the −ly charged electroscope, the leaves will either converge or diverge.

(*a*) If the leaves of the −ly charged electroscope converge, while those of the +ly charged electroscope diverge, the charge on the body is +. Shown at A^1 and B^2 in Fig. 69. (*b*) If the leaves of the −ly charged electroscope diverge, while those of the +ly charged electroscope converge, the charge on the body is −. Shown at A^2 and B^1. (*c*) If the leaves of both electroscopes converge, the body is uncharged.

In the first instance (*a*), when a +ly charged body approaches a +ly charged electroscope, by reason of the first law of electrostatics (§ 110), that portion of the electroscope's charge which is in the plate is repelled into the leaves, which therefore diverge to a greater extent. When a +ly charged body approaches a −ly charged electroscope, more of the − charge is attracted into the plate than was there before, leaving less in the leaves, which consequently converge. The same arguments—*vice versa*—apply with a −ly charged body. When an uncharged body is brought near, the leaves of the electroscope converge, whether it be +ly or −ly charged, because the *capacity* of the plate is increased, and it consequently takes up more of the charge than before, leaving less in the leaves (§ 134).

117*a*. **To ascertain if the Charge in an Electroscope is + or −.** If the kind of charge in an electroscope is unknown; to ascertain what its charge is, it is only necessary to bring near to it a known +ly or −ly charged body. If the leaves of the electroscope diverge in the presence of a +ly charged body, and converge in the presence of a −ly charged one, the electroscope is +ly charged. If, on the contrary, its leaves converge when a +ly charged body is brought near, and diverge when a −ly charged body is present, its charge is −. This will be clear from the experiments in the last paragraph.

118. **How to tell if a Substance be a Conductor or an Insulator of High Pressure Electricity.** Charge an electroscope by influence, either +ly or −ly.

(*a*) Take, say, 18 inches of string, tie a small weight, such as a metal button, to one end, and hold the other end in the hand. Let the string hang down at full length, hold it over the electroscope, and allow the button to come into contact with the plate: the charge on the electroscope will gradually leak away to earth through the string and your body, proving that string in this case is neither a very good insulator or a very good conductor.

(*b*) Charge the electroscope again, pass the wet fingers along the string from end to end, and proceed as before. When the end of the string touches the electroscope, the charge will be lost almost immediately, proving that the act of rendering the surface of the string damp makes it a better conductor than it was before.

(*c*) If a piece of cotton be used, the charge will slowly leak through it.

(*d*) If a piece of silk thread or twist be used, it will be found that little or no effect is produced on the electroscope, proving that silk is a good insulator of high pressure electricity.

(*e*) If the cotton or silk be damped from end to end, the electroscope will discharge itself through them almost immediately, as was the case with the damp string.

Solid substances, such as sticks of wood, metal, sealing-wax, ebonite, glass, or strips of cloth, paper, cardboard, etc., may be tested by holding one end in the hand, and touching the plate of the electroscope with the other.

The rods of sealing-wax, ebonite, or glass, if perfectly clean and dry, will be found to be very good insulators: but if their surfaces be in the least degree damp, (as is very likely to be the case with the glass rod, unless it be warmed) they will allow the charge to slowly pass away. Wood, cardboard, paper, cloth, etc., though practically insulators of low pressure electricity, will, in the present case, be found to be good conductors; the charge leaking away through them to earth. A rod of brass or any other metal will, of course, allow the charge to escape instantaneously.

119. **Electrification of Conductors.** Hitherto, when we

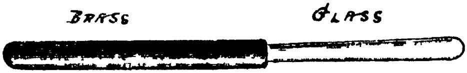

FIG. 70. BRASS TUBE WITH INSULATING HANDLE.

have wished to obtain a charge of electricity, we have electrified by rubbing, such insulating substances as glass, ebonite, sealing-wax, etc. All substances however, whether they be insulators or conductors, if rubbed with some other substance, will become electrified.

(*a*) Take a piece of brass tube in one hand, rub it briskly with flannel or with fur, and bring it near the plate of an electroscope. It will be impossible to detect the faintest sign of a charge. Why is this? The simple reason is that the charge, as soon as developed, runs away through the brass rod and the body to earth.

(*b*) Slip the tube on to one end of a dry glass or ebonite rod, as shown in fig. 70, so as to insulate it from the body and earth. Again excite it and present it to the electroscope: the leaves will diverge, showing the presence of a charge which has been unable to run away through the insulating rod.

120. **To maintain a P.D. between an Earth-connected Conductor and the Earth, work must be done.** When we held the brass rod in our hand in the first of the above experiments, it was what electricians call *earth-connected*, or, in other words, it was uninsulated. When the brass rod is rubbed, say, with fur, we charge it, *i.e.*, we develop electrification upon its surface, and as a consequence, a difference of potentials is set up between it and the earth: but as it is connected with the earth by a conductor, this difference of potentials is immediately equalised, or, in other words, the rod is discharged. If we wished to keep up the difference of potentials, we must keep on rubbing, *i.e.*, we must do constant work.

121. **The two Electrical States, + and −, are developed simultaneously and equally.** When we rub two bodies together, + electrification is developed on one, and − electrification on the other. When glass and silk are rubbed together, the glass becomes +ly electrified, and the silk rubber −ly electrified. When ebonite and fur are rubbed together, the ebonite becomes −ly electrified and the fur +ly electrified. Furthermore, the − charge on the silk is exactly equal in amount to the + charge on the glass; and the + charge on the fur is likewise equal to the − charge on the ebonite.

122. **The Frictional Series.** Following is a list of substances so arranged, that if any two of them be rubbed

together, the one which stands highest in the list will be +ly electrified, while that which stands lowest in the list will be −ly electrified.

The Frictional Series.

+ Furs.
Flannel.
Ivory.
Paper.
Smooth glass.
Cotton.
Silk.
Rough glass.
Metals.
India-rubber.
Ebonite.
Sealing-wax.
Resin.
Sulphur.
Vulcanised india-rubber.
Gutta-percha.
Collodion.
− Amalgamated surfaces.

The farther apart the substances are in the list, the greater the P.D. developed. Thus when flannel and smooth glass are rubbed together the flannel becomes +ly electrified, and the glass −ly electrified; but if glass and silk be rubbed together, the glass is +ly, and the silk −ly electrified.

When silk and glass are rubbed together they of course become electrified; but if the silk be amalgamated, the effect, *i.e.* the P.D. between the rubbed glass and the silk, is increased. One reason for this is that glass and amalgamated surfaces are much farther apart on the above list, than are glass and plain silk.

123. **Electrostatic Induction or Influence.** When an electrified body is brought near an unelectrified body, the portion of the latter nearest to the charged body becomes electrified with a charge of opposite sign, thus, if a +ly charged ball be hung up by a silk thread in the middle of an empty room, the floor, ceiling, and walls of the room will have a — charge *induced* or *influenced* upon them.

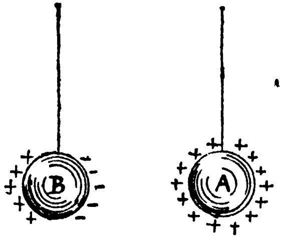

FIG. 71. INFLUENCE.

If a +ly charged ball A (Fig. 71) be brought near to an uncharged ball B, the portion of B nearest to A will be —ly charged, while the farther side will be +ly charged. Directly the charged ball is moved, however, the other ball resumes its former uncharged state. This is said to be due to *electrostatic induction* or *influence*.

124. **Experiments on Influence** (Fig. 72). (*a*) Provide two spherical conductors of brass (or of wood covered with tinfoil) mounted on insulating stands of varnished glass, or two eggs mounted on clean and warm wine glasses will do. Place them in contact, and bring up to them a charged glass rod. Hold the glass rod as shown in the figure, and

while it is there, separate the two balls from each other. Take away the glass rod and test the two balls by means of a proof plane and electroscope. That which was nearest the glass rod will be found to have a − charge, while the other will have a + charge. Had the charged glass rod been removed before the balls were separated, they would of course be found to have returned to their previous neutral condition. When the two balls are in contact, they may be considered as forming one conductor. When the + ly charged glass rod is brought near, in the position shown in the figure, it induces or influences a charge of opposite sign on that portion of the conductor nearest to it, viz., the right-hand ball; while it repels a charge of the same sign to the left-hand ball, *i.e.*, the part of the conductor farthest removed from it.

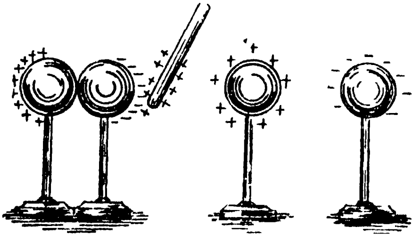

FIG. 72. INFLUENCE.

(*b*) Arrange apparatus as shown in Fig. 73. A cylindrical conductor with rounded ends mounted on an insulating stand of varnished glass, is placed about four feet distant from an uncharged electroscope; or at such a distance that when an excited glass or ebonite rod is held over the conductor in the position shown, no movement of the gold leaves can be detected. Now connect the conductor with the electroscope by means of a wire. When either the excited glass or ebonite rod is held over the conductor, a charge of the opposite sign will be attracted into the cylindrical conductor, and a charge of the same sign will be repelled into the electroscope. While the conductor is under the influence of the excited rod, by means of an insulating stick of ebonite or glass, detach

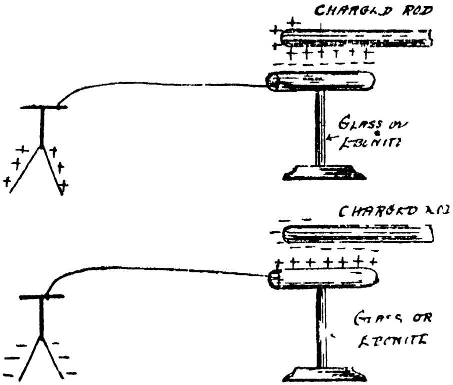

Fig. 73. Experiments on Influence.

the wire from the plate of the electroscope. It may now be proved by testing, that the repelled charge retained by the electroscope is of the same sign as that on the charged rod.

Thus, when an excited ebonite rod is used, it will be found that the electroscope's charge is —, for the leaves will diverge still further if an excited ebonite rod be brought near, but will converge in the presence of an excited glass rod. When an excited glass rod is used, the electroscope's charge will be + ; for the leaves will diverge still farther in the presence of an excited glass rod, but will converge in the presence of an excited ebonite rod.

125. **Theory of Influence.** When a body is + ly charged, it has a surplus of electricity upon it (§§ 45 and 46), of which it tries to rid itself by discharging into a neighbouring body, or the earth. It tends to discharge itself into the nearest body. A deficit of electricity (− electrification) is therefore occasioned on all parts nearest the charged body, ready for the + charge to equalise.

If a body is −ly charged, it has a deficit of electricity upon it, consequently a surplus of electricity (+ electrification) collects on all parts nearest the charged body, ready to discharge into it and make up its deficit. (See § 136.)

126. **To charge a Gold-Leaf Electroscope by Influence.** The student is now in a position to understand how and why it is that a gold-leaf electroscope may be charged by influence (§ 116).

The plate, the brass rod connecting it with the gold leaves, and the gold leaves themselves, may be considered as one insulated conductor (Fig. 74). When a charged body approaches the plate of an uncharged electroscope, the electrical equilibrium of the latter is disturbed; but if the charged body be removed without touching the electroscope, the latter will return to its neutral condition. Supposing the body to be + ly charged: it attracts − electrification to the plate, *i.e.* the part nearest to itself, and repels + electrification as far as possible, viz., into the gold leaves. The leaves consequently open out, showing the presence of a charge, the charge being of the same sign as that on the influencing body. When the plate is connected with

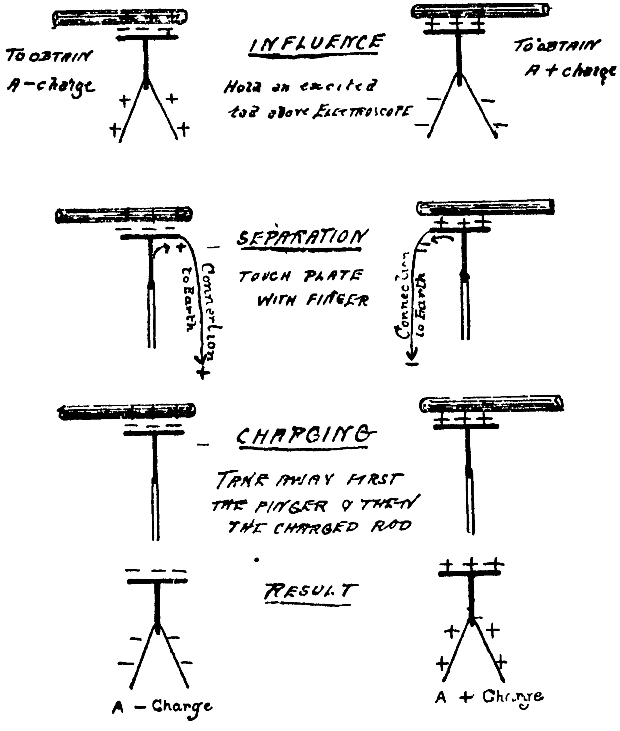

FIG. 74. CHARGING AN ELECTROSCOPE BY INFLUENCE.

earth by touching it with the finger, the − charge on the plate is not affected, as it is *bound* or *held* by the charge on the rod. The + charge in the gold leaves is being repelled by the charge on the rod, and as it has now an opportunity of getting farther away, it does so, escaping through the body to earth, and leaving the leaves uncharged, consequently they converge. To all appearance there is now no charge in the electroscope, but this is not so, there is the − charge accumulated in the plate and bound there by the presence of the charged rod. If the rod be now removed, this − charge distributes itself evenly over the plate, rod, and leaves of the electroscope, which latter thereupon diverge with a − charge.

When a −ly charged rod is used, a similar action takes place, except that the bound charge is + and the repelled charge −, and when at last the electroscope is charged, it is with a + charge.

127. **An inclosed insulated charged Body influences an Equal and Opposite Charge.** Following up what was said in § 124 anent influence; if a silk-suspended charged metal ball be lowered into the interior of an uncharged hollow conductor, such as a tin can, influence will take place; and an equal charge of opposite sign will be induced or influenced on the inside and bottom of the can, while a charge of the same sign will be repelled to the outside, and to earth. If the can be placed upon an insulating stand, the repelled charge on the outside may be tested by means of an electroscope and proof plane, and will be found to be of the same sign as that on the ball (Fig. 75).

128. **Charge resides on the Surface. Biot's Experiment.** When electricity moves along in the form of a current, it is supposed to flow through the substance of the con-

ductor: but when electricity is at rest on a conductor, in the form of a charge, it resides only on the surface; and in the case of hollow conductors, on the outer surface.

The apparatus for Biot's experiment is shown in Fig. 76. It consists of a metal ball mounted on a varnished glass stand, and two hollow brass hemispheres, each provided with an insulating handle of varnished glass. These hemispheres may be held together, one each side of the ball, and inclose it as in a shell.

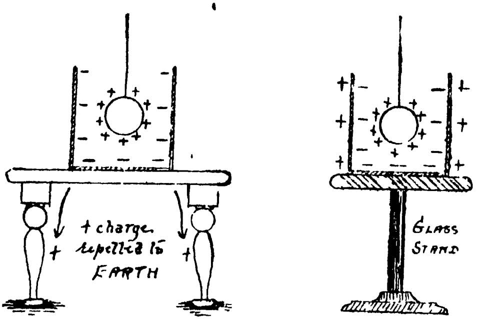

FIG. 75. AN INFLUENCED CHARGE IS EQUAL AND OPPOSITE.

Charge the ball from an electrical machine (§ 132), and make sure that it has a charge by testing it with a proof plane and an electroscope. Next present each of the hemispheres to the electroscope, and they of course will be found to be uncharged. Now, holding the hemispheres, one in each hand, by means of their insulating handles,[1] bring them together so as to inclose the ball;

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[1] It is hardly necessary to observe that the handles should not be grasped as shown in the figure, but by their extremities.

then take them apart, and test by bringing up to the electroscope: there will be a divergence of the leaves in each case, showing that both are charged. Test the ball, and not the faintest sign of a charge will be found.

When the hemispheres are brought together so as to inclose the ball, they and the ball form practically one conductor, so that the charge on the ball distributes itself over the new surface. When the hemispheres are taken away, they carry the charge with them, leaving the ball uncharged.

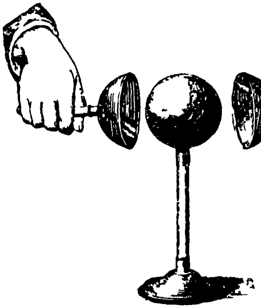

Fig. 76. Biot's Experiment.

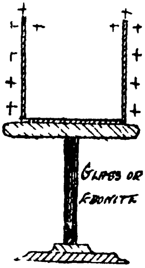

Fig. 77. Distribution of Charge on a Hollow Conductor.

129. **Charge on Hollow Conductors.** (Fig. 77.) Give a charge to an insulated hollow conductor, such as a tin can, a tea-pot, a metal bowl, etc., and test it all over by means of a proof plane and electroscope. No charge whatever will be found right inside, but on the outside, and especially at the edges, the presence of the charge may be readily detected. Nevertheless, a charged hollow conductor would be discharged if touched on the inside or

outside. The only case in which a free charge can be kept on the interior of a hollow conductor, is when an earth-connected conductor is lowered into the interior of the hollow conductor, without touching it, of course. Under these circumstances, part of the charge on the hollow conductor goes inside and acts inductively on the ball, attracting unlike electrification into the ball, and repelling like electrification to earth.

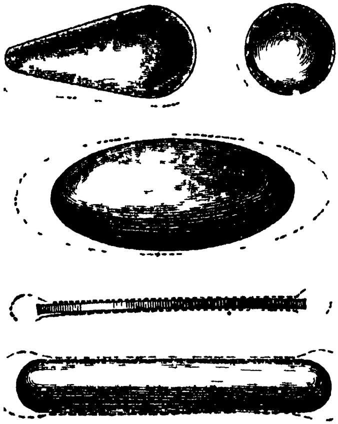
FIG. 78. DISTRIBUTION OF ELECTRICITY ON CONDUCTORS.

This apparently contradicts what is shown in Fig. 75; but there, it must be remembered, the charge inside is not *free*, but is *bound* by the presence of the charge on the ball.

130. **Distribution of Electricity on Conductors. Density.** The distribution of a charge of electricity on a conductor, depends upon its shape. If the conductor be a sphere (Fig. 78), the distribution or density of electricity will be uniform over its entire surface, as indicated by the dotted lines. If it be a disc, the density will be greater at the edge than on the flat surfaces. In the figure, variously shaped conductors are shown. *The density is greatest where the curvature of the surface is greatest.* Thus it is that the density on a charged body

is greater at the edges and sharp corners than anywhere else. The student may for the present associate the idea of *density* with that of *thickness* of electricity at any particular part of the surface of a body; but only because this is an easy way of expressing what is observed.

Although the density may vary at different parts of a charged conductor, according to its shape; being greatest at the edges and nothing in the interior, if it be hollow (§ 129): yet, *the potential is the same at all parts of the conductor, inside and out, whatever its shape may be.* If such were not the case, there might be two points on the *same* conductor at different potentials, but this of course would be impossible (§ 48).

131. **Action of Points.** If a charged body have a point upon its surface, it will be incapable of keeping its charge for any length of time, especially if it be near any earth-connected body, for the charge will stream off from the point. Or if an earth-connected point, such as a needle held in the hand, be presented to a charged body, the body will be gradually and silently discharged. Such discharge is called *discharge by convection*, or *convective discharge.* The density of electricity at the point becomes so great, that the neighbouring particles of dust or air are electrified, and consequently repelled; flying off with some of the charge.

132. **Frictional and Influence Electrical Machines.** An electrical machine is an apparatus for developing great difference of potential, and as a consequence, charges of high pressure electricity may be obtained from it.

The so-called *frictional electrical machine* is seldom if ever used now; but we illustrate and describe it here, because a knowledge of its action is necessary to the student.

P is a plate of glass mounted on a spindle, so that it may be revolved by means of the handle, in the direction shown by the arrow. As it revolves, it passes between two amalgamated leather rubbers, R R^1, one on each side of the plate. By this means, + electrification is developed on the glass. After any part of the plate has passed

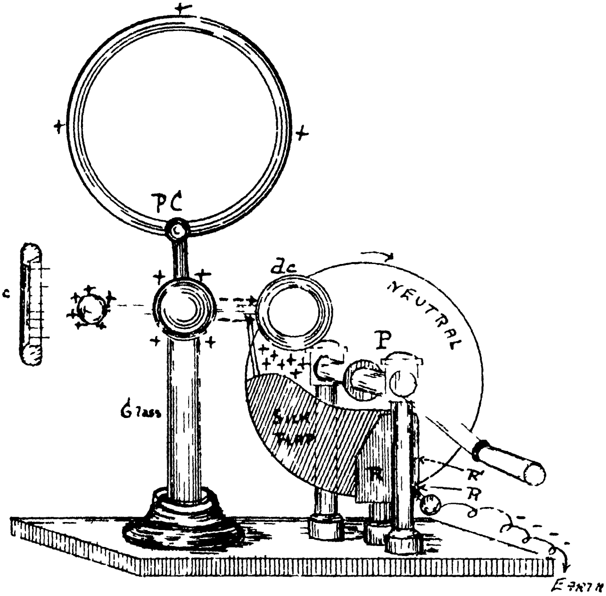

FIG. 79. FRICTIONAL ELECTRICAL MACHINE.

between the rubbers, it passes upwards with its + charge until it comes opposite to the *discharging combs*, *d c*, which are in metallic connection with the insulated *prime conductor*, P C, of the machine. This term prime conductor is an old-fashioned one, terminal would be a better word.

When the charges on the glass plate come opposite the discharging combs, they effect the charging of the prime conductor in the following manner.

The prime conductor, with its discharging combs, is at first in an uncharged condition. The + charges on the plate by influence attract − electrification to the combs, repelling + to the prime conductor: the density of this induced or influenced electrification on the points of the comb becomes very great, and by the action of points (§ 131) the − electrification streams off on to the glass plate, neutralising the + charges there, and leaving the prime conductor in a state of + electrification. The parts of the glass plate, after passing the combs, return to the rubbers in an uncharged or neutral condition, and therefore all ready to be re-excited. In order that as little as possible of the charge may be lost on the journey from the rubbers to the combs, silk flaps inclose that portion of the glass plate. *d c*, to the right of the figure, represents a section of a discharging comb, showing the points.

Fig. 80 represents a Wimshurst influence machine, a type superior to all others. Though simple in construction, the explanation of its working, depending as it does upon influence (hence its name), is far too complicated for a beginner to understand: therefore we shall content ourselves with a simple description of its construction.

Two circular glass plates, as near together as possible, are so mounted that they revolve in opposite directions, when the handle of the machine is turned. These plates have on their outer faces, radial *sectors* of tinfoil, as seen in the figure. If any one sector has the slightest initial charge, it acts inductively or influentially on all the sectors on the other plate as they pass by, and these sectors, having charges induced on them, react on the sectors of the first plate. By an arrangement of fine wire brush *dischargers* and *collecting combs*, the induced or influenced charges are "collected" from the sec-

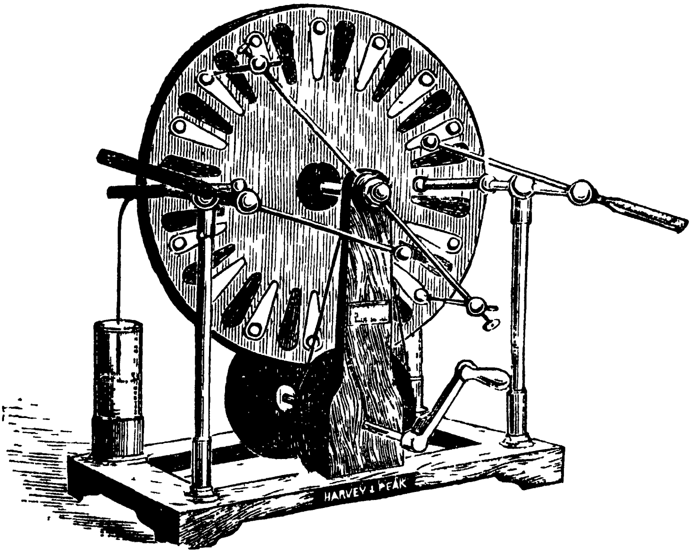

Fig. 80. Wimshurst Influence Machine.

tors, and led away to the terminals of the machine. There are two Leyden jars[1] at the back, one of which is connected to each terminal, thus serving to increase their capacity (§ 134).

133. **Electric Discharge.** If a body at a + potential and a body at a − potential, be connected by a conductor, a discharge of electricity will take place from the one to the other, and the potential difference between them will be equalised. Similarly, if a +ly or a −ly charged body be connected with the earth, discharge will take place, and the body will be brought to zero potential, *i.e.* the potential of the earth (§ 47). If the P.D. be very great, the discharge will take place before the two charged bodies, or the charged body and the earth, are quite joined by the connecting conductor. It will take place through the air, in the form of a sudden spark, accompanied by a report. Electric discharge across the air is not always accompanied by a spark and report (§ 131).

134. **The Condenser.** When two flat conducting plates are placed opposite each other, with a sheet of insulating material between them, the arrangement is termed a *condenser*. A condenser may be described as an apparatus for "condensing" or "accumulating" a charge of electricity. The action of a condenser depends upon influence, and the attraction of unlike charges. If an insulated conductor be far removed from other conductors, for instance, hung up in the middle of an empty room; a certain amount of electricity may be put into it or abstracted from it, before its potential is raised or lowered to

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[1] See § 135.

a given degree. But if that conductor be near to (but not touching) another conductor, especially if the latter be earth connected, the *capacity* of the first conductor is increased ; in other words, it will be possible to impart to it, or take away from it, more electricity before its potential is raised or lowered to the same degree as before.

Fig. 81 represents the simplest form of condenser. G. P. is a glass or ebonite plate about one foot square, with a sheet of tinfoil about eight inches square gummed on each side. The glass plate fits upright in a slot cut in a block of wood, which serves as a stand. The tinfoil sheets are placed in the middle of each side of the glass plate, so that there is a strip of glass two inches wide all round. The glass, where not covered by tinfoil, should be varnished. The tinfoil sheets, marked *a* and *b* in the drawing, are called the *coatings* of the condenser. They should have each a little strip of tinfoil, *c c*, glued on, so as to form a kind of catch for the end of a wire, when it is desired to connect the condenser with anything.

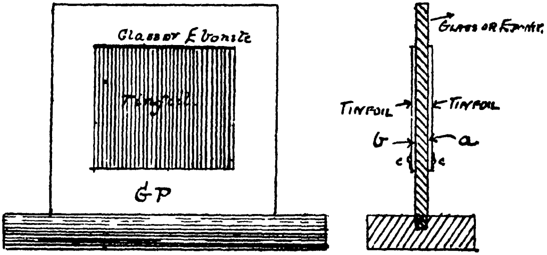

FIG. 81. SIMPLE CONDENSER.

The insulating material which separates the coatings of a condenser, and which may be glass, ebonite, gutta-percha, air, or other good insulator; is, when used for this purpose, called the *dielectric.*

135. **The Leyden Jar.** The Leyden jar, so called because it was first made in the town of Leyden, is simply a convenient form of condenser. It consists generally (Fig. 82) of a wide-mouthed glass jar, coated inside and outside, on the bottom, and half way up the sides, with tinfoil. The remainder of the glass, inside and out, is coated with shellac varnish, to prevent the accumulation of moisture. An ebonite or wooden top is provided, which supports a brass rod, terminating at its upper extremity in a ball; and at its lower, in a short piece of chain, which serves to connect the rod and ball with the inner coating.

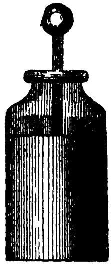

FIG. 82. LEYDEN JAR.

136. **Experiments with Condensers.** Take a simple condenser (of course a Leyden jar will do as well) (Fig. 83). Call one tinfoil sheet *a* and the other *b*. Connect *b* to earth and *a* to the terminal of an electrical machine; *a* becomes charged, say, +ly, and this + charge acts inductively or influentially across the dielectric (glass, ebonite, etc., as the case may be) on *b*, attracting − electrification into *b*, and repelling +. This influenced − charge reacts on the + charge on *a*, pulling it on to the inner surface of *a*, and so making room for more. The *capacity* of *a* being thus increased, it takes up more positive electrification, which in its turn induces or influences a still greater −

charge on *b*. And so the action goes on, the two charges hugging and binding one another, and in fact actually compressing the dielectric between them, though of course in an infinitesimal extent.

We should explain the above action by saying that a surplus of electricity (§ 47) is "pumped" on to *a* by the machine: while a deficit is influenced on *b*.

As *a* becomes +ly electrified; *b*, the nearest conductor to *a*, gives up some of its electricity to earth, thus leaving itself in a state of deficit, ready to receive the overcharge of *a*, for *a*'s surplus is ready to discharge itself at the first opportunity into the nearest body, in this case, *b*.

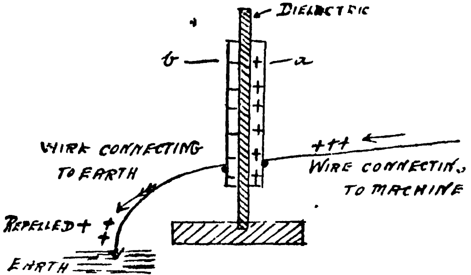

FIG. 83. CHARGING A CONDENSER.

Another and better explanation is as follows:—

In figure 84, C C is a closed chamber of metal, divided into two parts, *a* and *b*, by a watertight elastic partition, *e*, of gutta-percha for instance; *a* and *b* are connected by a pipe, *p*, in which is inserted a hand-pump, P. The whole arrangement is filled with water. If the pump is worked, water is forced in the direction of the arrow, *i.e.* into the chamber *a*; at the same time it is extracted from *b*, causing the elastic diaphragm to bulge out, as shown by the dotted line. There is a surplus of water in *a* and a deficit in *b*, and if the pump were suddenly taken away, so that *a* and *b* might be connected by a free pipe, *e* would fly back to its former position, and the surplus of water in *a* would discharge through the pipe into *b*. This is pretty much what may be supposed to occur in the case of the condenser: as fast as electricity is "pumped" by the electrical machine into *a*, electricity flows into the earth to make up the deficit there, and leaving a deficit in *b*, the nearest body to *a*. If *a* has a surplus (+ electrification), a deficit (— electrification) must of necessity exist somewhere, and as a matter of fact, it will exist in the nearest earth-connected conductor to *a*, which is *b*.

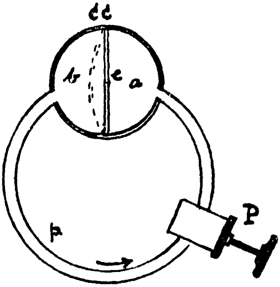

FIG. 84.

A Leyden jar, or condenser, cannot be charged unless the other coating is connected to earth. This goes to support what we have just remarked; for instance, in the case of the simple condenser, if we had not connected coating *b* to earth, we could not have got any appreciable charge into *a*.

Similarly, a condenser cannot be discharged unless both coatings be connected with one another, either directly, or through the earth.

Experiment. Charge a Leyden jar and stand it on an insulating stand. Although it be highly charged, the knob may be touched with impunity, for the surplus on the one coating cannot get round to the deficit on the other coating, as the jar is insulated.

FINAL REMARKS.

The student who has done the Author the honour of going carefully through this little work, will, it is hoped, be in a position to enter into the initiatory study of some of the many practical applications of Electricity and Magnetism, no mention of which is made here. At the same time, he should remember that he has ventured but a very little way into the domain of pure science. He will find that much more theoretical knowledge is necessary, to enable him to thoroughly understand any one of the more important applications—Telegraphy, Telephony, Electric Lighting, Traction, Transmission of Power and Electro-metallurgy. In a future *Second Book of Electricity and Magnetism*, the Author hopes to advance so much farther as will enable the Student to pass the second stage Examination of the Science and Art Department.

END OF PART III.

MIHI CURA FUTURI.

QUESTIONS.

PART III. ELECTROSTATICS, OR ELECTRICITY AT REST.

N.B. In answering these questions, give sketches wherever possible.

1. What is the derivation of the word "*Electricity*"?

2. How may electrification be developed?

3. How would you electrify a glass rod?

4. Of what is "electric amálgam" composed, and for what purpose is it used?

5. What other substances besides glass can be easily electrified by friction, and how?

6. Say what you know about electrical attraction.

7. How would you electrify brown paper?

8. What precautions are necessary in order that experiments in electrostatics may succeed?

9. Describe experiments illustrating electrical repulsion.

10. Why is it that an electrified body first attracts and then repels an unelectrified body?

11. What is the difference betwixt (*a*) the attraction between an electrified and an unelectrified body; and (*b*) the attraction between two electrified bodies?

11*a*. Do electrified bodies always attract each other?

12. *Define:* — electrification, charge, + charge, — charge.

13. What is the first law of electrostatics?

14. If an electrified body attracts another body, can you be certain that the latter is electrified? Give reasons for your answer.

15. Explain the difference between an electroscope and an electrometer.

16. Describe with sketches, the construction of the gold-leaf electroscope.

17. What is the difference between an electroscope and a galvanoscope; and between an electrometer and a galvanometer?

18. To what uses may the gold-leaf electroscope be put?

19. How would you ascertain whether a body was electrified or not?

20. What are proof planes, and how are they used?

21. How would you charge an electroscope negatively?

22. How would you charge an electroscope positively?

23. In how many ways is it possible to charge an electroscope? Say which you think is the best method, and why.

24. You have two electroscopes before you, one +ly and the other −ly charged. If the leaves of both converge when a body is brought near them, is this a proof that the body is charged? Give reasons for your answer.

25. Is it possible to charge an electroscope +ly by influence, by means of a +ly charged body?

26. How could you charge an electroscope −ly by means of a −ly charged body? Is there any objection to the method of charging you describe?

27. Having two electroscopes before you, one +ly and the other −ly charged, how would you ascertain whether the charge on a body was + or −?

28. Explain the effect of damp air in lessening the insulating properties of a body.

29. Given a substance, say how you would find out whether it was a conductor or an insulator of high pressure electricity.

30. A brass tube held in the hand becomes electrified if rubbed with a piece of fur or flannel ; how is it that you cannot detect its electrification by means of an electroscope ?

31. How would you so arrange matters that the electrification of a metal tube or rod could be detected by means of an electroscope ?

32. When is a body " earth-connected " ?

33. What is meant by saying that, "*to maintain a potential difference between an earth-connected conductor and the earth, work must be done*" ?

34. If a piece of ivory is rubbed with a cat's skin, what would be the electrification developed on each ?

35. How would you electrify ivory positively ?

36. It is required to electrify two copper tubes, one −ly, and the other +ly ; what would you use to rub the tubes with in each case ?

37. Say what you know about influence.

38. Sketch and describe three experiments on influence.

39. Three uncharged metal balls, mounted on glass supports, are placed in a row, so that they touch one

another; they are numbered 1, 2, and 3, ball No. 2 being in the middle. A charged ebonite rod is held within half an inch of ball No. 3, and while it is there the balls are separated from one another. If you now test each of the balls by means of a proof plane and electroscopes, what would be their electrical condition?

40. Give a theory regarding electrostatic induction or influence.

41. Describe exactly what takes place when a gold-leaf electroscope is charged +ly by influence.

42. When a charge on one body induces a charge on another body, what relation do the two charges bear to each other?

43. (*a*) A tin can standing on the table has a charged metal ball lowered inside it, but without touching; (*b*) the tin can is placed on an insulating stand, and the charged ball again lowered inside. If in each case the outside of the can were connected by a wire to an electroscope, what would be the effect upon the latter, and why?

44. Describe any two experiments to prove that the charge on a conductor resides wholly on the surface.

45. Does a charge always reside on the surface of a conductor?

46. *Define:* capacity, density, convective discharge.

47. Has "density" anything to do with "potential"?

48. Why is it not possible for two parts of a charged conductor to be at different potentials?

49. How can the charge on a body be taken from it without touching it?

50. There are two kinds of electrical machine. What are they, and why are they so named?

51. Give a sketch, and a full description of the construction and action of a frictional electrical machine.

52. An insulated body is highly charged; how would you discharge it (*a*) so as to get a spark; (*b*) silently.

53. *Define:* condenser, Leyden jar, silent discharge.

54. Sketch and describe the construction of a simple condenser.

55. Sketch and describe the construction of a Leyden jar.

56. Explain the action of points.

57. Explain the action of a condenser.

58. Under what circumstances is it impossible to charge a Leyden jar or condenser?

59. Describe some experiments with a Leyden jar.

60. Describe an hydraulic analogue illustrative of the charge and discharge of a condenser.

LIST OF APPARATUS.

The apparatus marked by asterisks may be omitted if desired.

PART I.—MAGNETISM.

1. Piece of lodestone.
2. 1 lb. iron filings.
3. 1 lb. small iron tacks.
4. 3 feet steel wire, ⅛″ diameter.
5. Bunsen burner, tubing, and blowpipe. For hardening steel wire.
6. 6 pieces hardened steel, about 6″ × ¾″ × ¼″. One piece magnetised.
7. 6″ smooth file.
8. Copper wire stirrup (Fig. 3).
9. 1 piece soft iron, 6″ × ¾″ × ¼″.
10. 12 yards No. 18 copper wire covered with india-rubber and cotton.
11. (The coil mentioned in § 11 may be made by winding a few yards of the above wire on to a tube made of stiff paper or cardboard.)
12. 12 bichromate cells (Fig. 32). Plates about 5″ × 3½″ amalgamated zincs; stoneware jars. (This includes cells wanted for use in Part II.)
13. 3 gallons chromic acid solution (§ 64).
14. Pair 10″ bar magnets with keepers, in case.
15. 3½″ electro-magnet (Fig. 53, right hand).

*16. 4″ horseshoe compound magnet.

17. 2 oz. strongest nitric acid.
18. 6″ test tube.
19. Wooden clamp stand.
20. 4″ magnetic needle and stand (Fig. 9).
21. 4″ dip needle and stand (Fig. 10).
22. 6″ horseshoe permanent magnet and keeper.

23. Sheet of glass, 12″ square, with white paper pasted on one side.
24. Tin pepper-box, for sprinkling iron filings.
25. Glass tube, 10″ × ⅝″ diameter, fitted with corks.
26. 1 lb. steel filings.
27. Piece soft iron, 10″ × 1″ × ¼″ (§ 33).
28. Simple compass.
*29. Mariner's compass.
*30. 3″ astatic needles.

PART II.—ELECTROKINETICS.

31. 2 plates of zinc and copper, 4″ × 2″, with copper wires soldered to them.
32. Glass beaker, 4″ deep × 3″.
33. 2 feet glass rod, ¼″ diameter.
34. ½ lb. mercury.
35. 1 lb. sulphuric acid.
*36. Daniell cell (Fig. 30).
*37. Bunsen cell (Fig. 31).
*38. Fuller cell (Fig. 33).
*39. Leclanché cell (Fig. 34).
40. 1 lb. copper sulphate.
41. 1 lb. potash bichromate.
42. ½ lb. sal ammoniac (ammonium chloride).
43. ¼ lb. black oxide of manganese (in lumps).
44. ¼ lb. crushed carbon (in lumps).
45. Piece of paraffin wax.
*46. 10-volt incandescent lamp.
47. 2 feet No. 30 german silver wire.
48. 6 yards No. 14 electric light wire (§§ 71 and 72).
49. 2 small magnetic needles, 1″ long (§ 74).
50. Œrsted stand (Fig. 46), without needle.
51. Simple Œrsted stand (Fig. 47), without needle.
*52. Simple horizontal galvanoscope (Fig. 48). This will do also for simple vertical galvanoscope (Fig. 49).
53. Horizontal galvanoscope (Fig. 50).
54. Suspended solenoid, stand, and mercury cups (Fig. 52).
*55. Astatic galvanometer (Fig. 57).
56. Hoffmann's voltameter (Fig. 58).
57. 2 pieces sheet lead, 4″ × 1½″ × ⅛″; 2 bindscrews for same.

PART III.—ELECTROSTATICS.

58. 2 sticks of sealing-wax, 8″ × ⅞″ diameter.
59. 2 pieces glass tube, closed and rounded off at one end, 24″ × 1″ diameter.
60. Piece brass tube closed at one end, 12″ long. To fit above (Fig. 70).
61. Piece of silk.
62. "Electric amalgam."
63. 2 sticks of ebonite, 8″ × ½″ diameter.
64. Piece of flannel.
65. Piece of fur.
66. 1 dozen pith balls.
67. Skein of silk twist.
68. (Stand mentioned in item 21 will do for experiments in Part III.)
69. 2 gold-leaf electroscopes (Fig. 67).
70. 3 proof planes, with ebonite handles; various shapes (Fig. 68).
71. 2 spherical conductors on insulating stands (Fig. 72).
72. Brass ball, 1″ diameter (§ 127).
73. Insulating stand (Fig. 75).
74. Apparatus for Biot's experiment (Fig. 76).
75. 10″-plate Wimshurst influence machine (Fig. 80).
76. Simple condenser (Fig. 81).
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CHISWICK PRESS.—C. WHITTINGHAM AND CO., TOOKS COURT,
CHANCERY LANE.